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Pelagic Tunicates in the Plankton of South-eastern Australian Waters, and their Place in Oceanographic Studies

By

HAROLD THOMPSON, M.A., D.Sc.

With a Statistical Analysis of Data on Total Plankton

By

G. L. KESTEVEN, B.Sc.

(Division of Fisheries—Report No 8.)

MELBOURNE, 1942

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War time economy requires reduction in the Council's expenditure on publication. It is hoped that the adoption of the photo-lithographic process will be for a brief period only.

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FOREWORD.

In attempting to arrive at a well-founded estimate of the pelagic fishery resources of Australian waters - and this is the primary objective of the current Commonwealth investigations - use must be made of the technique of oceanographical science. The latter is concerned with, inter alia, the detection of important changes in currents and water conditions generally, together with their effect on the amount and distribution of plankton (floating plant and animal life, upon which pelagic fish depend for their sustenance). Conditions at sea are never static - they vary from month to month, from year to year, and even in irregular cycles of years. Roughly speaking, the course of the fisheries varies accordingly. Hence, just as no State can afford to be without its meteorological service, so it is being increasingly realised that no important fishery should fail to have at its disposal the knowledge (and even, as sustained studies reach fruition, the fore-knowledge) derived from an oceanographic service. The function of the latter is first of all to determine what are the normal conditions of a region (and hence to determine its character and possibilities in the fishery sense), and thereafter to detect variations from the normal, and to forecast the probable course of events in the near future. These variations give rise to the more or less violent fluctuations so disturbing to the fisheries - times of glut and scarcity, absence or presence of fish in particular regions, and so forth.

No fisheries scientist is long at work before he is made aware of the desirability of being in a position to answer questions of the type - "How long will fish be so scarce as they are at present?", "Are the fish stocks gone for good?", "Will the season be an early one?", or "Will the run of fish be good on this particular coast this year?". Thus it would be invaluable for the newly established salmon canneries on the New South Wales coast to know if and when the existing poor runs will be succeeded by normal runs in the estuaries. Given a reasonable period of prior study of cause and effect, the scientist can usually formulate fairly reliable answers or predictions in connection with such matters.

To produce highly reliable results, oceanographic, like meteorological observations, should be made on a large and representative scale. This is seldom possible in fisheries investigations which have the location and sampling of fish shoals as their first objective.

This is the first of several reports on the oceanographic operations carried on incidentally in conjunction with the exploratory work aiming at the evaluation of Australian pelagic fishery resources. The investigations, carried out by the motor-vessel "Warreen", commenced in May 1938, and the period from that date till January 1941 is dealt with here. During this period the whole south-east Australian area was repeatedly traversed, and oceanographic observations were made as frequently as they could be without interfering with the more specific fishery investigations. Since the observations were not specifically planned so as to be repeated at definite intervals of time at equally spaced-out stations representative of the whole area, it is sought here to detect trends and recognise

indications rather than to establish conclusive quantitative findings. It may be possible in normal times in the future to carry out, as in other countries, a more ideal programme with the aid of vessels of the mercantile marine and of the Navy. To the latter a full hydrographical knowledge of the area is of particular value (for example it may not be out of place here to direct attention to the necessity of having a detailed knowledge of currents and eddy systems where floating mines are concerned).

Sufficient has possibly been said above to indicate that the prosecution of oceanographic work is not merely an academic or purely scientific exercise. Certainly no marine biologist considers it such. The writer hopes however that there is some further justification for issuing the report in that it deals with a much more extensive survey of Australian plankton than has hitherto been made, and in particular considerably extends the previously existing knowledge of the distribution of pelagic Tunicates in these waters, from which most of the species dealt with have not previously been recorded.

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SUMMARY.

An intensive study has been made of the pelagic Tunicates of the south-eastern Australian area. They comprise, next to Crustacea, the chief portion of the zooplankton, and are suitable to serve as "indicators" of changing oceanographic conditions which affect the course of the fishery.

Only circumtropical and sub-tropical species occur - no species typical of subantarctic (cold-water) influences being found, even in the Tasmanian region, which is not sharply differentiated from that off the mainland. Comparison of species and their relative numbers with those in other regions indicates a much closer affinity with south Japanese and Philippine and Indo-Malayan than with Californian conditions. Hence there is a distinct probability that the pelagic fisheries of south-eastern Australia will develop on west - rather than on east - Pacific lines.

From the occurrence of an unusual number of rarer circumtropical and sub-tropical species in 1939-40, and from the simultaneous reduction in numbers of the more indigenous species, it appears that abnormally warm conditions prevailed during the period named. There was also a progressive decline in the volume of plankton from 1939 onwards. These conditions adversely affected the fisheries.

Unlike many other plant and animal groups in the plankton, the Tunicata are much more abundant in these sub-tropical waters than in the great fishing areas of the colder portion of the Northern Hemisphere. The total volume of plankton is however only of moderate proportions.

The concentration of Tunicates is much greater in the upper 50 or 100 metre water layer than at greater depths; and several times greater in the warmer than in the colder months of the year. Lesser and more uniform concentrations occur at greater depths. These facts afford some explanation of the surface shoaling of pelagic fishes, and indicate that future investigations will yield most reliable results and be most economically pursued if chiefly confined to the upper water layers in the warmer season of the year.

A high degree of reliability characterises the qualitative aspect of intensive plankton investigations. While caution is necessary in making deductions from quantitative results, those based on standardised vertical hauls have considerable value.

Pelagic Tunicates in the Plankton of South-eastern Australian Waters, and their Place in Oceanographic Studies

I. METHOD OF INVESTIGATION.

Quantitative plankton study in the comprehensive sense was initiated by an intensive survey conducted during the Plankton Expedition, and the methods used are described by Hensen (1895). Owing to the vastness of the oceanic water masses the most highly organised investigations are admittedly imperfect, but it must be acknowledged that the continuous traverses made by world expeditions have afforded results of a high degree of consistency. Naturally many gaps are always left to be filled, and many hypotheses are formulated for future proof or disproof.

There are one or two almost insurmountable obstacles to the making of exact quantitative plankton investigations at sea. One is the lack of uniformity of distribution of the phyto- and zooplankton. This is referred to by Hardy (1936). Russell & Colman (1934) also remark on the violent fluctuations found in the volumes of net catches owing to the presence or absence - in the track of the net - of the naturally intermittent swarms of pelagic Tunicates. They state that only on a few days during the year were really large catches made - the largest (with the 1 metre stramin net, towed for half an hour) being 110,000 salps - with which we may compare the largest catch by M.V. "Warreen", with similar gear and in the same time, of 60,000 - i.e. something of a comparable order. An examination of all quantitative plankton results reveals an inevitable spread between the lowest and largest catches made under approximately the same conditions. By increasing the number of sampling hauls, however, the inescapable fluctuations in amounts caught are smoothed out, and it is usually possible to obtain sufficiently consistent results to form an estimate of the comparative density of distribution in different areas and in different seasons. Typical examples of the outcome of such work are, e.g., to be found in the reports of Jespersen (1935) and Hart (1937).

The avoidance of discrepancies introduced by comparing catches made in different seasons (particularly important when colder waters with their greater variations are being studied) can only be achieved by having synchronised investigations carried out by a series of vessels spaced over the area by prearrangement, and it is of interest to note that, under the auspices of the European International Council for the Exploration of the Sea, hydrographic and plankton investigations of this nature were being organised prior to the present war.

Another difficulty arises from the great variation in size and activity of movement of the different constituents of the plankton. This is overcome to some extent by employing a range of nets - the smaller of fine silk and narrow mesh, to retain comparatively small organisms, the larger of coarser material and mesh to filter the water more rapidly and to capture and retain the larger organisms. The nets used by M.V. "Warreen" in the investigations discussed here were the N.70, N.100, and N.200 of the Discovery Expedition type.* These, together with the methods of their use, are described by Kemp and Hardy (1929) in the first volume of the reports of that Expedition. There still remains the difficulty of combining the results of these different nets; and there is an omission from the picture of the most minute organisms, whose computation demands special sea-water filtration and further treatment not practicable on a small vessel. More recent discussions on these methods are to be found in the work of Lohmann (1903, 1912); Kokubo and Tamura (1931); Gardiner (1931); Kunne (1933); Allen (1934); Seemann-Nielsen (1935,1938); Hardy (1936); Ricker (1938); Clarke (1940); and Winsor and Clarke (1940).

There can be no question about the value of the qualitative results obtained in plankton investigations - the presence or absence of the key organisms cannot fail to be revealed by repeated hauls of a series of nets; and, as will be shown below, even the presence of a series of rare species can be detected during a short visit by the latter to an area. Quantitative results however, owing to the above limitations, obviously require cautious interpretation. Yet there can be a high degree of reliability in, e.g., repeated catches made by means of short standard vertical hauls. Gardiner (1931) using a silk net of the N.70 type referred to above, compared the results of some of a large number of vertical hauls with larger collections made by horizontal hauls, and showed that 77 per cent. of such vertical hauls might be expected to give values lying within ±33 per cent. of the mean (or true) value; of the remainder, one-half would lie within ±40 per cent. of the mean, while there would be occasional extremes up to ±90 per cent. Russell & Colman (1934) also remark on the comparative reliability of the results of vertical hauls made in the Barrier Reef region. Winsor & Clarke (1940), comparing vertical hauls of a 75 c.m. scrim net, found the standard deviation of a single haul was about 53 per cent. and compared this with 43 per cent. and 47 per cent. found by Gardiner & Kunne respectively. For the single horizontal haul however, the standard deviation was much higher (as much as 93 per cent. was suggested).

Clearly, then, results of some value are to be expected from the regular use in vertical hauls of these types of net in a circumscribed area. Obviously over a vast area a very large variation in numbers of organisms caught is to be expected. Thus Lohmann (1933) states that the numbers of Copelata caught by a vertical net per 100 metres varied,

* N.70 - A fine silk net with a circular mouth of 70 centimetres diameter. It was used vertically (N.70 V.) at various levels - from depths of from 1000 to 500 metres, 500 to 250 metres, 250 to 100 metres, 100 to 50 metres, and 50 metres to the surface, and was automatically closed (except in the last case) on reaching the upper limit of depth shown. It was used also in horizontal tows (N.70 Hor.) of 30 minutes duration.

N.100 and N.200 - Stramin nets with diameter of opening 100 and 200 centimetres respectively. Towed horizontally for 30 minutes per haul, and retaining only the larger types of plankton organisms.

in the great area covered by the Plankton Expedition, from 6 to 50,000 - the latter figure being attained in the Indian Ocean. Mackintosh (1934) refers similarly to much variation in the richness of the Antarctic plankton - a single haul yielding anything from a dozen to 200,000 organisms. The total variation in the catches of M.V. "Warreen", while great, was of less extent than this; and within the same season and a restricted region, it was quite small. A statistical treatment of the data is given in Appendix II of this paper.

The seasonal variation in warmer regions is not nearly so great as in colder; thus Russell & Colman (loc. cit.) found that in the Barrier Reef region the ratio of the lowest average catch with a coarse silk vertical net (September) to the highest (January) was 1 to 4.1.

McIntosh (1937) corroborates the value of vertical hauls, stating that samples from vertical closing nets give a much more reliable indication of quantity distribution than those from towed nets, whose depth and speed vary with weather and other conditions.

As part of the fishery investigations conducted on M.V. "Warreen", it was thought to be of importance to interpose, as and when possible, definite plankton and hydrographic investigations. During the period under review (May, 1938 - January, 1941) the whole south-eastern Australian area was traversed at intervals of time in order to obtain data on the distribution of pelagic fishes, and thus, although the oceanographic work could not be based on a definite plan of repeating specific stations at quite definite intervals throughout the year, there was actually some approximation to such an ideal. The results cited below are therefore based on a reasonable degree of repeated sampling over the whole area in all seasons of the year.

In analysing the catches the following method was followed: each collection, if too large to be examined as a whole for identification and enumeration of its constituent species, was placed in a 100 cc. stoppered graduated cylinder, and the liquid was made up to the mark. A uniform suspension was obtained by repeated inversion. By means of a wide-bore tube, graduated to 10 cc., one-tenth was quickly removed and placed in a graduated petri dish. The Tunicates - or a definite proportion of them if the numbers were very large - were then selected for identification and enumeration. The total numbers of each species in the whole collection were then calculated. (In the case of very large collections, an aliquot part was treated as above).

Assuming perfect filtration of water by the N.70 net drawn through 100 metres vertically, the resulting numbers would be those contained in a column containing approximately 38 cubic metres of water. Since of course filtration is imperfect (to varying degrees due partly to clogging by gelatinous animals such as salps) the quantitative results fall on the low side. The value of basing conclusions only on the results of a goodly number of hauls, in order to mitigate to a large extent this and other causes of fluctuation, is of course obvious.

II. PELAGIC TUNICATES IN THE SOUTH-EASTERN AUSTRALIAN REGION.

1. Classification.

The classification of pelagic Tunicates followed here in general is chiefly that adopted in the Handbuch d. Zoologie, where the Copelata are dealt with by Lohmann (1933), the Pyrosomida by Neumann (1934, 1935), and the Desmomyaria by Ihle (1935). For the Cyclomyaria the classification of Garstang (1933) is followed. The following reservations are made with regard to certain species.

With regard to Copelata little remark is called for. *Oikopleura intermedia* Lohmann is recognised here as including *O. microstoma*, described by Aida (1907-8) from Japanese waters. Tokioka (1940) suggested that *O. cornutogastra* is a form of *O. fusiformis*, but the writer finds these to be distinct species. *Fritillaria borealis* is represented in the collections only by f. *sargassi*, f. *typica* or *acuta* not being taken even in the cooler Tasmanian waters. The absence of *F. tenella* Lohmann was rather surprising in such a complete collection of warm water forms, but it is possible that this form is identical with *F. megachile*, which occurred rather frequently in the S.E. Australian collections.

A critical examination of the extensive Pyrosoma material disclosed no grounds for recognising more than one species, either on account of size, shape, or structure of the corms or of the zooids. All the material is referable to the species *Pyrosoma atlanticum* Péron, which it seems to be difficult to separate clearly from *P. giganteum* Lesueur. Neumann (loc. cit.) states that Pyrosoma could be classified either with the Ascidians or the Thaliaceae, but that it is probably best to place the Pyrosoma group under Thaliaceae, along with Cyclomyaria and Desmomyariae.

Only two species of Cyclomyaria (Doliolida) were recognised in the material, these being two of the commonest found elsewhere - *Doliolella gegenbauri* Uljanin and *Doliolum denticulatum* Quoy and Gaimard. Here the revised terminology introduced by Garstang has been adopted, and *D. gegenbauri* has been regarded as including *D. tritonis* Herdman, the latter name now being reserved for such gonozooids and phorozooids as show an extension of the ventral gill slits in front of the 5th muscle band. These species were also taken by the Barrier Reef Expedition. Garstang has shown that they occur also in New Zealand waters, along with *Doliolina müllieri* and *Doliolella mirabilis*.

Eighteen of the nineteen clearly established species of salps have occurred in these collections (*Ihlea punctata* Forskål and *Ihlea asymmetrica* Fowler were absent; but these may yet prove to be forms of one species, which so far has not been found in the Pacific, although it occurred in the "Siboga" collections from the Indian Archipelago). Sewell (1926) is probably justified in regarding as mere variants or intermediate forms (coming within the extremes of variation of structure exhibited by the respective established species) the following:- *Cyclosalpa pinnata* sub. sp. *polae* Sigl; *Salpa maxima* f. *tuberculata* Metcalf; *Pegea confoederata* var. *bicaudata* Quoy and Gaimard; and *Salpa fusiformis* f. *aspera* Chamisso. Of these forms only *S. fusiformis* f. *aspera* has clearly been recognised in the "Warreen" collections. *Thalia longicauda*, which is probably a form of *T. democratica*. has previously been recorded from the Pacific only from the east coast of Australia (Apstein, 1906b). It was not noted

by Metcalf (1918) from Philippine collections, by Sewell (loc. cit.) from collections from the Indian Ocean, by Ihle (1910) from the "Siboga" material from the East Indies, or in the Barrier Reef Expedition collections. The collections of *Thalia democratica* made by the "Warreen" were very extensive in quantity, but superficial inspection did not reveal any individuals exhibiting the slight differences of structure attributed to *T. longicauda*, a form which has never been adequately studied.

A list of the species found so far in south-eastern Australian waters is given in the appendix to this paper. The systematic and general data, with keys to identification, will form a separate publication.

2. Total Numbers of the Various Species taken in South-eastern Australian Waters.

Copelata.

Oikopleura longicauda	269,912
" *fusiformis*	57,485
Fritillaria pellucida	46,654
Oikopleura rufescens	45,718
" *dioica*	15,159
Megalocercus huxleyi	11,294
Stegosoma magnum	9,751
Oikopleura albicans	8,897
" *cophocerca*	3,597
" *cornutogastra*	3,483
Fritillaria formica	1,580
Oikopleura parva	1,536
" *intermedia*	1,263
Fritillaria borealis f. *sargassi*	815
Fritillaria haplostoma	300
" *fraudax*	211
" *megachile*	150
Tectillaria fertilis	143
Fritillaria bicornis	100
Althoffia tumida	4
Kowalevskia tenuis	3
Bathochordaeus charon	1
Chunopleura microgaster	1

Pyrosomatida.

Pyrosoma atlanticum (colonies)	12,815+

Desmomyaria.

Thalia democratica	1,421,652
Ihlea magalhanica	132,144
Salpa fusiformis	25,057
Traustedtia multitentaculata	6,531
Brooksia rostrata	2,765
Salpa maxima	1,561
" *cylindrica*	1,184
Iasis zonaria	914
Pegea confoederata	682
Cyclosalpa pinnata	236
" *bakeri*	110
Thetys vagina	91
Ritteriella amboinensis	41
Metcalfina hexagona	2
Cyclosalpa affinis	2
" *floridana*	1
" *virgula*	1
Ritteriella picteti	1

Doliolida.

Doliolum denticulatum	112,794
Dolioletta gegenbauri	28,863
Doliolidae (blastozooids)	13,717

Thalia democratica is therefore by far the most characteristic of the pelagic Tunicates in south-eastern Australian waters. The next most important salp - *Ihlea magalhanica* though it predominates at times in the most southern (Tasmanian) area, occurs in less than one-tenth of the numbers of the former species. This species, and also *S. maxima*, have hitherto been regarded as rare, but they are at times quite numerous in south-eastern Australian waters. Third in the list of salps is *Salpa fusiformis*, and the remaining species occur in relatively small numbers. Among the Copelata the outstanding species is *O. longicauda*, other important species being *O. fusiformis* and *O. rufescens*, with *Fritillaria pellucida* easily the most abundant of the Fritillaria species. Of the two Doliolida species *D. denticulatum* is by far the more abundant. The younger colonies of *Pyrosoma atlanticum*, the only Pyrosoma species found, are extremely abundant at times.

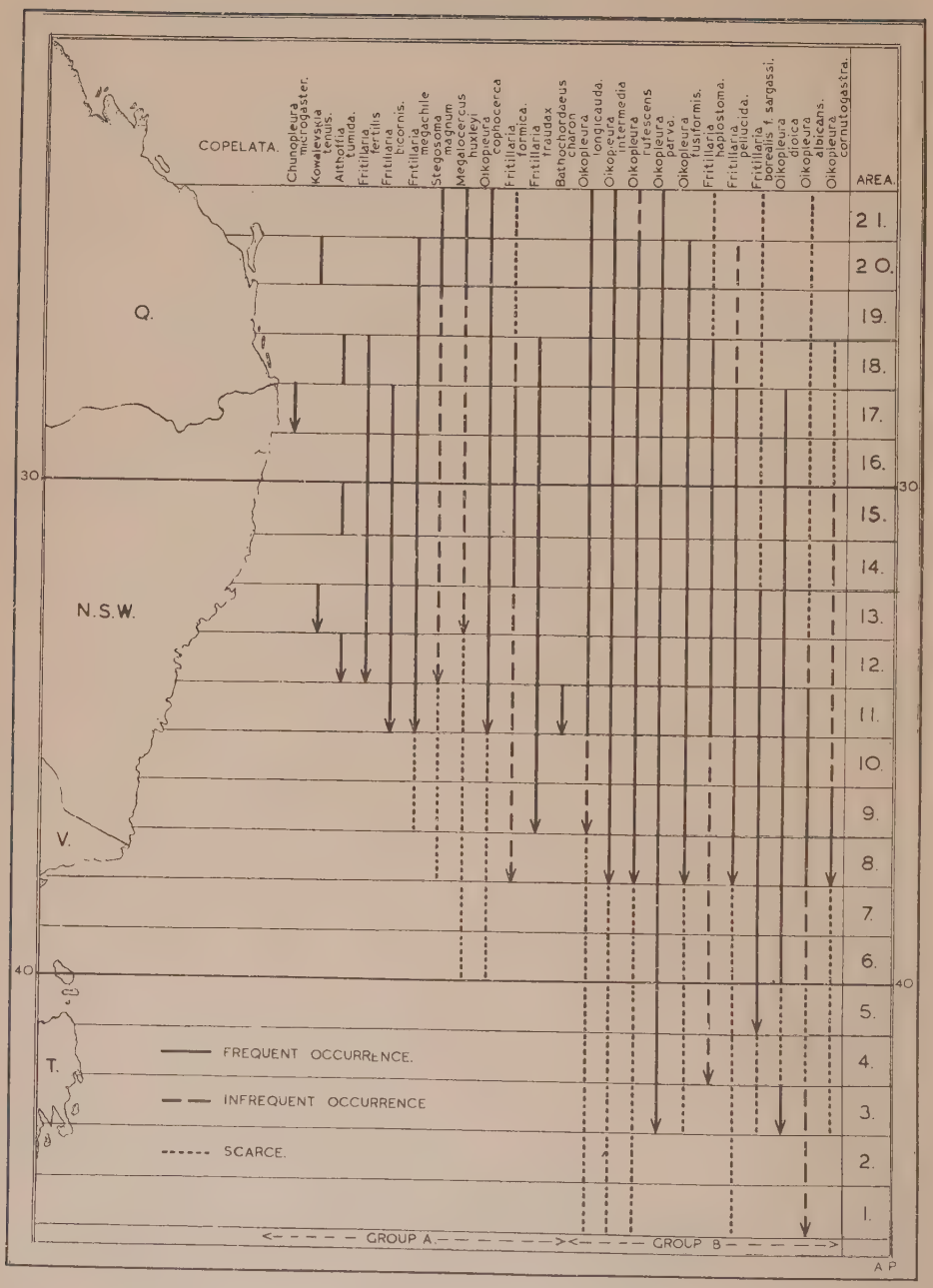

Fig. 1 - Copelata - General distribution from north to south.

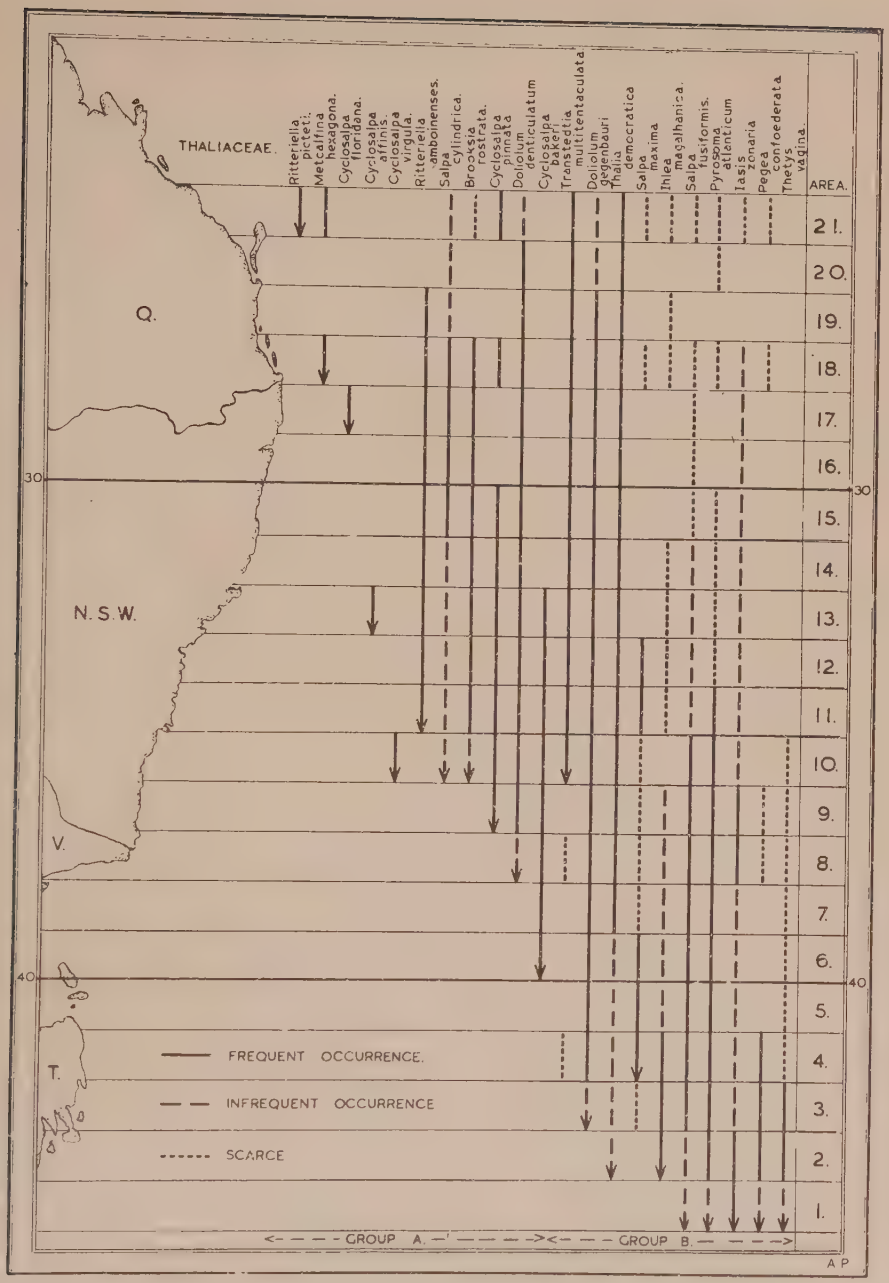

Fig. 2 - Thaliaceae - General distribution from north to south.

3. Distribution of Species.

In Figs. 1 and 2 are set out the chief and subsidiary regions of occurrence of the 44 species of pelagic Tunicates taken up to January, 1941, by M.V. "Warreen". The diagrams are arranged so that on the extreme left are placed the species confined in their distribution to the more northerly and warmer waters, and on the right the species which are most common towards the more southerly and cooler waters. Approximately half of the species are confined to the area north of Bass Strait (Group A), while the remainder (Group B) are found also in Tasmanian waters, those on the extreme right being on the whole most plentiful there. The commonest species (*O. longicauda* and *T. democratica*), being particularly eurytherm in nature, and thus tolerant of a wide range of conditions, naturally occupy intermediate positions in the diagrams.

Generally speaking, in the case of the Copelata, the chief centre of density of occurrence is towards the north; no species has this centre in the south, although approximately half of the species can penetrate to Tasmanian waters. Hence the chief value of the Copelata as indicators of changing oceanographic conditions will be in the unusual appearance in certain years of the rarer species which occur in Group A. As will be shown later, an unusual number of these species occurred in 1939-40.

These remarks also apply in general to the Thaliaceae, although some Salp species (e.g. *Ihlea magalhanica* and *Thetys vagina*) are more typical of Tasmanian waters than of those north of Bass Strait, and there will likely be seasons in which unusual penetration of these species *en masse* towards the north will serve as a useful indication of a similar trend of colder water influences.

Adequate plankton investigations should be continuously maintained to follow these changes over a sufficient period of years to establish the normal, together with the range of variation from normal; the accompanying variations in the results of the commercial fisheries should at the same time be correlated as far as they can be.

It should be noted that, on the evidence of a fair number of hauls of the plankton nets made from M.V. "Warreen" during cruises to South Australian waters in February and December, 1939, there is a tendency for a reduced number of species to be taken off the Victorian coast, and a still smaller number off South Australia. The actual total numbers taken were as follows:-

	Victoria		South Australia
O. longicauda	853	...	4,122
O. fusiformis	276		
O. dioica	200	...	2,448
O. cornutogastra	106		
O. rufescens	33	...	23
M. huxleyi	27		
O. cophocerca	26		
F. pellucida	20		
F. borealis (f. *sargassi*)	10		
F. megachile	0	...	29
Thalia democratica	1,020	...	17,846
Salpa fusiformis	40	...	470
Pegea confoederata	0	...	312
Cyclosalpa pinnata	0	...	152
	(14 species)		(8 species)

It is of importance, particularly in studying the possible migration of pelagic fish from the east coast to Victorian and South Australian waters, to obtain indications such as the above of the degree of common occurrence of other pelagic organisms. It is of interest to note that Serventy (1941) has shown that, of the several species of tunny found off the east coast, only one - the southern bluefin - has so far been proved to occur in South Australian waters, which in this respect also exhibits a reduction in number of species. It will be of further interest to determine in fuller detail the linkages of South Australian oceanographic conditions with east and west (Pacific and Indian Ocean respectively).

4. The Relative Importance of Tunicates in the Plankton.

In the course of the study of each of the plankton collections of M.V. "Warreen", a note was made of the animal group which, from visual inspection, obviously formed the chief constituent. (In a negligible number - approx. 4 per cent. of the 1463 hauls - no individual group predominated).

The following table shows, for each month, the number of hauls, expressed as a percentage of the whole, in which the various groups were clearly predominant:-

	Crustaceans	Tunicates	Coelenterates	Chaetognaths	Molluscs
Jan.	53.7	32.8	8.6	2.1	2.8
Feb.	45.6	35.6	4.4	2.2	0
Apr.	58.0	31.0	11.0	0	0
May	62.4	12.1	5.1	1.9	1.3
June	70.0	23.3	1.7	0	1.7
July	75.3	11.1	4.9	1.2	0
Aug.	72.2	11.4	10.1	1.3	0
Sept.	53.2	40.7	4.5	1.7	2.3
Oct.	78.1	18.9	6.3	0.6	0.6
Nov.	60.0	31.2	4.8	0.8	0
Dec.	56.3	31.2	6.3	0.9	1.8
Monthly Average	62.5	25.4	6.2	1.2	1.0

It is seen that Crustaceans easily take first place as the predominant group in the plankton all through the year; especially is this the case in the winter months (June to August) and in October. Tunicates (chiefly salps) are the only other group which frequently predominates, doing so chiefly in spring and summer. Russell & Colman (1935) found that Tunicates formed, on the average, half the catch in hauls of the stramin net in the Barrier Reef region, but only 2.7 per cent. of fine silk net catches. Only the Crustaceans were greater in amounts - Copepods alone comprising 71.1 per cent. of the zooplankton in the vertical hauls.

These two groups so greatly overshadow the others in quantity as to render discussion of the percentage occurrences of the latter of little consequence.

Tunicates are therefore particularly suitable for study as indicators, especially as they are in addition, with the one exception of *Oikopleura dioica*, all oceanic forms, and typical of certain conditions.

III. THE USE OF TUNICATES AS INDICATORS OF CHANGING OCEANOGRAPHIC CONDITIONS.

Although, as will be shown below, there was evidence of a progressive decrease in the volume of total plankton after 1938, this was due, in the case of the Tunicata, to a decrease in numbers of the commoner species. Actually, in 1939, and in part at least of 1940, the number of species present showed a distinct increase, caused by the occurrence of the rarer forms.

Copelata: Normally, only from one to six species occur in any one haul, although from seven to nine species are to be taken on rare occasions. On no occasion in 1938 were ten or more species taken in one location, whereas this occurred three times in 1939 and four times in 1940. (Actually these exceptional occurrences were limited to the period between May 1939 and April 1940). The increased number was caused by the appearance of rare species of the circumtropical type. Thus, with the exception of the occurrence of *Kowalevskia* and *Fritillaria megachile* in 1938, the rarer species were found only in the period between April 1939 and April 1940. These species included: *Althoffia*, *Chunopleura*, *Bathychordaeus*, and the *Fritillaria* species *fraudax*, *fertilis*, *bicornis*, *megachile* and *haplostoma*.

Salpa, Pyrosoma, and Doliolids: Here again an increased number of species - due to the occurrence of circumtropical forms - was noted in 1939. The commonest species (*Thalia democratica*, *Ihlea magalhanica*, *Salpa fusiformis*, *Traustedtia multitentaculata*, *Brooksia rostrata*, *Salpa maxima*, *Pyrosoma*, *Doliolum denticulatum*, *Dolioletta gegenbauri*, *Cyclosalpa pinnata* and *C. affinis*) were taken more or less regularly every year, but were, on the whole, less numerous in 1939 than at other times. On the other hand, ten of the least common forms (*Salpa cylindrica*, *Iasis zonaria*, *Pegea confoederata*, *Thetys vagina*, *Ritteriella amboinensis*, *Metcalfina hexagona*, *Salpa fusiformis f. aspera*, *Cyclosalpa bakeri*, *C. floridana* and *C. virgula*) made their best showing in 1939 and early in 1940. Among the rarest forms of all, *Metcalfina hexagona*, *Cyclosalpa floridana* and *C. virgula* occurred only in 1939; whereas only one species (*Ritteriella retracta*) was found only in 1938. This rare species is however difficult to differentiate and may have been overlooked on one or more occasions.

It can reasonably be inferred that beginning in 1939, and lasting at least for some months into 1940, if not longer, there was evidence of an unusual incursion to south-eastern Australian waters of tropical and sub-tropical Tunicates, and that concurrently there was some decrease in the quantities of the commoner and more indigenous species. These indications are suggestive of an unusually strong warm water influx, such as would transport tropical or sub-tropical organisms not normally present in the area, and at the same time adversely influence the more indigenous organisms.

It is noteworthy that by the year 1940. and still later in the early part of 1941, fishing conditions were abnormally affected, by this or some other cause unknown. Thus bluefin tuna were unusually scarce in both years, and more restricted with regard to the area of their distribution. The barracouta and Australian salmon fisheries were abnormally poor, anchovy were very scarce (although pilchard were more plentiful than in the preceding years). The northern bluefin tuna was captured much further to the south than normally is the case. Many other unusual features were noticed in the fisheries.

It is of the utmost importance to ascertain the periodicity of the occurrence of such unusual conditions, since the whole course of the commercial fisheries is modified by them, and since foreknowledge of the probable onset and duration of such conditions would undoubtedly be of value to the industry. The writer, working on the haddock of the North Sea, found that highly favourable conditions for the stock occurred approximately three times in ten years. It is of interest to note (Dakin & Colefax, 1933) that in October 1932 a great invasion of *Thalia democratica* from the north-east occurred in the coastal region (in the vicinity of Sydney, New South Wales). These authors state that such an occurrence had only been noted two or three times in the past ten years. Correlation between such events and the course of the fishery should be made. It may be more than mere coincidence that 1932 and 1940 (a year in which the same salp was again found in conspicuously large numbers very close inshore) were outstandingly good years for pilchards.

Reference may be made to the use which has been made in other regions of pelagic Tunicates as indicators of changing oceanographic conditions. Bowman (1922) drew attention to the possible connection between the influx of salps and of Atlantic water to the North Sea region. Russell & Hastings (1933) similarly drew attention to the possibility of pelagic Tunicates acting as indicators of movements of Atlantic water into the English Channel. Thompson & Frost (1935) indicated that the occurrence of different species of Copelata could be used to indicate the annual and seasonal variation in the degrees of occurrences of Arctic and Atlantic water in the Newfoundland fishing area, and that as a result, light could be thrown on variations in the results of the fisheries.

McKenzie (1939) traced large scale shoreward movements of Gulf Stream water in the Nova Scotian region through the unusual occurrences of *Iasis zonaria*. Aida (1907) and Tokioka (1940) stated that the more oceanic species of pelagic Tunicates on the Japanese coast are swept in during the season by the Black (Kuro-Sio) Current, and are scarce during the cold season. Essenberg (1926) similarly traced the relationship between the occurrence of different species of Copelata on the Californian coast and cold and warm water currents respectively. Schmidt (1909) showed the importance of *Fritillaria borealis* in tracing current movements in the Iceland area.

IV. SUB-DIVISION OF THE AUSTRALIAN AREA.

No substantial reason has been found, in this study, for subdividing the south-eastern Australian area, which is therefore considered here as a whole. The area covered extended from approximately the Tropic of Capricorn in the north to a few miles south of Tasmania.

Hedley (1903) gave names to the natural sub-divisions of the whole Australian area. Whitley (1932) published a revision of these. On the east coast he distinguished the Banksian, Peronian, and Maugean regions, the first extending south to Moreton Bay, Queensland, the second to Bass Strait, and the third to the south of Tasmania. Iredale (1939) states that all the studies in every group by Australian workers have confirmed these subdivisions. Clark (1916) from a study of a portion of the bottom fauna (starfish etc.) suggested a

somewhat different subdivision - the separation of an east Australian sub-region (extending from about 35°S. Lat. to 15°S. Lat.) from a south Australian sub-region lying south of 35°S. Lat. - the former merging northward into the East Indian (Indo-Pacific) fauna of the Torres Strait. There may in certain cases be some doubt, therefore, as to exact placing of lines of demarcation. Seemann-Nielsen (1934), studying the Ceratidae, distinguished 58 species from south-eastern Australian waters, but only 17 from the Great Barrier Reef region. Russell & Colman (1935) reported only 6 species of salps from the collections of the Barrier Reef Expedition (as compared with 18 obtained from the "Warreen" collections made in the region further south). Hence in the northern portion of the East Australian area there appears on this evidence to be some restriction in the variety of pelagic species to be found, possibly on account of the limitation of oceanic by neritic influences within the Reef. It is therefore probably justifiable to consider the south-eastern Australian area as terminating naturally at about the commencement of the Barrier Reef area to the north. Since, as will be shown later, there is no evidence of a subantarctic cold water influence being encountered towards the south, and since there is, towards the south, at most merely a gradual transition (marked by the dropping out of real circumtropical species and not by the intervention of typical cold water species), no ostensible reason exists, as far as this study is concerned, for the placing of a southerly limit to the area, the general physical conditions of which probably persist to a point many miles to the south of Tasmania.*

V. CHARACTERISATION OF THE SOUTH-EASTERN AUSTRALIAN REGION.

1. Characterisation from "Indicator" Species in the Plankton, and Diversity of Species.

As has been indicated above, the conception of utilising certain easily recognisable organisms in the plankton as indicators of the presence of the water conditions they typify has from time to time occupied the attention of oceanographers. The idea is attractive, since a ready means is provided of detecting marked deviations from the normal in the interchange of water masses drawn from different sources. Russell (1935) points out that, in an area where several water bodies mix, only the types of plankton animals found can give clues as to the origin of the waters, unless the salinity differences are sufficiently marked to do so; he also states that if plankton animals are to be used as indicators they should be practical indicators - hence the larger and more easily identifiable they are the better. The latter attribute would apply to the salp (*Salpa fusiformis*) shown by Schmidt (1909) and Bowman (1922) to be useful for indicating unusual incursions of Atlantic water in which it normally occurs, into the North Sea, where it does not normally occur; and to various Tunicate species (Russell & Hastings, 1933) carried at times into the English Channel from the Atlantic. It would not apply however, to the microscopic Tunicate *Fritillaria borealis*, which moreover, in one or other of its forms, is cosmopolitan.

* Mr. K. Sheard, from a preliminary study of the offshore and even the inshore crustacea in these collections, has informed the writer that he has found no justification for subdividing the south-eastern area. He considers, however, that a case can be made out for the existence of natural subdivisions when the problem is considered purely in the light of marginal reef and sand-dwelling animals subject to localised conditions.

Fig. 3 - Observations on *Rhizosolenia curvata* in the Southern Indian Ocean and south of Australia. (After Hart, 1937).

Fluctuations in the yields of fisheries are particularly embarrassing to the industry, yet they are ever-recurring, and any quick means of tracing their cause or even of anticipating them is of value. Thus the writer has found that a good cod fishery on the Newfoundland Banks is associated with a strong influx of Arctic water, which can be detected even from the jetties by the presence of the Tunicate *Oikopleura vanhoffeni* (Thompson & Frost, 1935). Similarly, the progeny of the cod and haddock spawning grounds situated to the south-west of Iceland are carried annually with the variations in the current-system. From these variations there result important fluctuations in the fisheries. Savage & Hardy (1935), and Hardy *et al.* (1936) discuss the influence of the occurrence of certain types of plankton on the great herring fishery of the North Sea. Hardy and Gunther (1935) cite the Crustacean *Euphausia superba* as apparently a key animal in the Antarctic macroplankton, where its study is of especial importance since it is directly the food of the blue and fin whales, just as allied species of Crustacea are part of the food of tuna in Australian waters. It is therefore highly important that, in Australian waters, the variations in the composition of the plankton - some of them obvious even to the surf-bather - should be correlated with fluctuations in the fisheries, and used, as far as they safely can be, to detect fluctuations in the current-systems and to anticipate the course of the fisheries in the immediate future. But as Künne (1937) says, the indicator concept is one which should be used only with careful regard to its necessary limitations. He points out that the fluctuation in the numbers of organisms is of importance, as well as the fluctuations in types.

In addition to their possible considerable use in a fisheries intelligence service, plankton indicator species can be of use to the hydrographer in interpreting physical data on current movements. To select a recent example, Hart (1937) showed how the Dinoflagellate *Rhizosolenia curvata* could be used as an indicator species in the Southern Ocean (Fig. 3). On a southgoing voyage this species was first met between the two curves of convergence (sub-tropical and antarctic) and can be used to trace the varying northward course of antarctic water, of which it is typical. All the heavier catches of this species were made in sub-antarctic water.

It is of importance to any study of Australian hydrographic conditions to glance at the important conclusions reached by Deacon (1937) on the movements of, and limits reached by, cold antarctic water. This author indicates that the origin of the ubiquitous antarctic bottom water which reaches 40°N. Lat. in the Atlantic is probably the S.W. and W. parts of the Weddell Sea. It incorporates water from the warm deep layer which exists throughout the whole of the antarctic zone, and the resultant highly saline bottom water flows north in the Atlantic, Indian, and Pacific oceans. It is the heaviest water in the sea. On all sides of the Pole, antarctic surface water also spreads north in a shallow surface layer till it reaches, at approximately 50°S. Lat., the *antarctic convergence* (Fig. 4), where it plunges abruptly to a deeper level to continue as the *antarctic intermediate current*. Where the southward moving deep water is opposed by a large volume of antarctic bottom water the former is forced up from below 2,000 metres to within 200 metres of the surface. Over this ascending warm deep water the northward moving antarctic surface water flows like a cascade to become the antarctic inter-

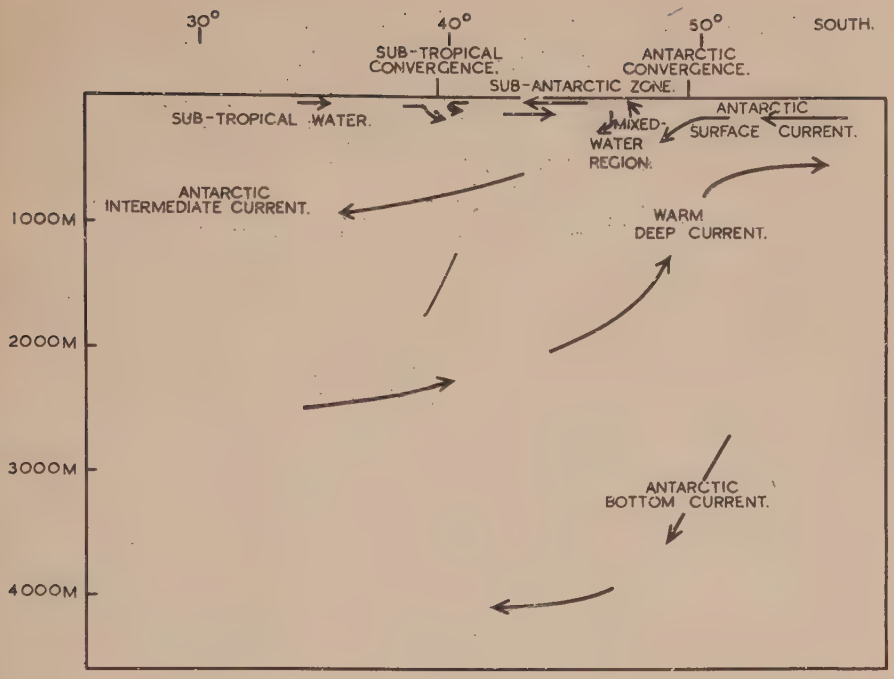

Fig. 4 - The vertical circulation of water in the South Atlantic Ocean. (After Deacon, 1937).

mediate current. Room is then left above for the warmer and lighter sub-antarctic (mixed) surface water, which continues the northward course to approx. 40°S. Lat., the position of the *sub-tropical convergence* with the south-going current of mixed water below the surface resulting. The region between approx. 47° and 40°S. Lat. is recognised as the *sub-antarctic zone*, in which the cold antarctic water influence is to some degree still felt. However, the approximate position of the sub-tropical convergence - the northern limit of this influence - varies, as shown in Fig. 3, and it appears that the whole of the Australian area lies well to the north of it. The fact that there is no real cold water influence in the latter area is further demonstrated by the character of the Tunicate species found, and is of considerable importance in enabling conclusions to be arrived at with regard to the nature and extent of Australian fishery resources.

It is now accepted that in cold-water regions the number of different species per genus to be found is very much restricted, though the total quantities are usually great, while in warm water regions there is a great diversity of species, not usually occurring however in great quantities. To take an example - Seeman-Nielsen (1934), working on the Ceratidae taken by the "Dana" expedition, found 58 species in collections from south-eastern Australian waters, which are sub-tropical in character, as compared with 33 species from the temperate portion of the New Zealand area, and only 3 species from the colder south-eastern portion of the latter. Later in this

paper it is shown that cold areas like those of N.E. North America, Iceland, and the North Sea have few species of pelagic Tunicates (the writer found only three species of Copelata in the 1921-1922 collections of the International Ice Patrol vessel in the Newfoundland Bank region, and two during a voyage round Iceland) whereas a sub-tropical region like that of south-eastern Australia has large numbers (at least 23). Very many other instances could be given. The rule appears to apply also to fishes. Thus in a cold area like that of Newfoundland there are fewer than 100 species of fish; there are many more species of fish in the southern (warmer) than in the northern (colder) Japanese area; and the number in Australian waters exceeds 2,000. This causes the fisheries of the latter region to have quite a specialised character, for as Hardenberg (1938) states, there are about 25 species of the herring (*Clupea*) type in the waters of the Indo-Australian Archipelago, as compared with about five in European waters. Hence, he continues, in tropical waters there is no "herring fishery" but a "fishery for several herring species." *There are more fish species, but fewer individuals of each.* Of the Barrier Reef region Russell & Colman (1934) say that in their general aspect the zooplankton catches were typical of those taken from warm waters - there was an appearance of transparency in the preserved material, and an absence of the fatty residue which appears at times in plankton collections from northern latitudes owing to the great numbers of large copepods and crustacea.* Thus, except for occasional swarms of salps, these authors found no single instance throughout the year of the very large swarms of larger animals, such as chaetognaths, medusae, copepods, or euphausiids, which in high latitudes give rise at times to plankton of a monotonous composition. From their observations, it also seemed likely that very similar conditions extend for a considerable distance north and south of the portion of the reef examined. (Perhaps we have here an explanation of the small size and the unusually low content of fat or oil exhibited by the pilchard of Australian waters, which feeds largely on these crustacea, whereas the same species of pilchard taken from New Zealand waters, where the plankton is, on existing evidence, richer, reaches a greater size and has a fairly high oil content†). Russell (1934) states that in Barrier Reef waters large shoals of atherines and small sardine-like fish are at times met, but that it is possible, though by no means certain, that their numbers and feeding capacity are small compared with the great numbers of pelagic fishes occurring in northern waters.

No new species of pelagic Tunicates were observed in the collections made from M.V. "Warreen", but many species were recorded for the first time from Australian waters. The two following tables indicate, for purposes of comparison, the variations in the occurrences of species in widely separated and distinctive regions.

* Mr. K. Sheard informs the writer that a general examination of the crustacea of these more extensive south-eastern Australian collections appears to disclose an increase in the oil content southwards. This is particularly noticeable in certain Copepod species and in the Euphausiid species *Euphasia similis*, *E. recurva*, *Thysanoessa gregaria*. The increase is much less marked in the neritic species *Nyctiphanes australis*.

† Hardenberg (loc. cit.), with regard to the demersal conditions of the tropical Java Sea region, states that the bottom fauna is much less than in European waters, and suggests that this is partly the cause of the small size attained by the flatfish. There are many species - even dwarf species - but few of each. This he states is a severe fishery handicap.

A. COELATA:

Species	AUSTRALIA M.V. "Warreen"	AUSTRALIA Great Barrier Reef Expedition	EAST INDIES Siboga Expedition (chiefly)	JAPAN	CALIFORNIA San Diego	NORTH SEA	NEWFOUNDLAND AREA, S.T. "Cape Agulhas"
Oikopleura longicauda	+	+	+	+	+	-	-
" *fusiformis*	+	+	+	+	+	+	-
" *rufescens*	+	+	+	+	+	-	-
" *dioica*	+	-	-	+	+	+	+
" *albicans*	+	-	-	+	+	-	-
" *cophocerca*	+	-	+	+	+	-	-
" *cornutogastra*	+	-	-	+	-	-	-
" *parva*	+	-	-	+	-	-	-
" *intermedia*	+	-	-	+	-	-	-
" *labradoriensis*	-	-	-	+	+	+	+
" *vanhöffeni*	-	-	-	-	+	+	+
Megalocercus huxleyi	+	+	+	+	-	-	-
Stegosoma magnum	+	+	+	+	-	-	-
Althoffia tumida	+	-	-	-	+	-	-
Kowalevskia tenuis	+	-	-	+	+	-	-
Chunopleura microgaster	+	-	+	+	-	-	-
Bathychordaeus charon	+	-	-	-	-	-	-
Fritillaria pellucida	+	-	+	+	+	+	-
" *formica*	+	-	+	+	+	-	-
" *borealis*(f.*sargassi*)	+	+	+	+	+	-	-
" *haplostoma*	+	+	+	+	+	-	-
" *fraudax*	+	-	-	+	-	-	-
" *megachile*	+	-	+	+	-	-	-
" *bicornis*	+	-	+	-	-	-	-
" *borealis*(f.*typica*)	-	-	-	+	+	+	+
" *venusta*	-	-	-	+	+	+	+
" *tenella*	-	-	+	+	-	-	-
Tectillaria fertilis	+	-	-	+	-	-	-
Appendicularia sicula	-	-	-	+	+	+	-
TOTAL	23	8	14	24	18	8	4

The following deductions may be drawn from these occurences:-

(i) Comparing the Australian region with the rich fishing regions of California, Newfoundland, the North Sea, and Japan, it is most striking that species which are indigenous in moderately cold water (e.g. *O. labradoriensis* and *F. borealis* f. *typica*) are completely absent from the former region, but are in varying degree typical of the latter areas. In addition, *O. vanhöffeni*, which is typically found in Arctic water, is one of the predominant Newfoundland species in the cold current flowing down the east coast. In unusually cold seasons (which incidentally produce the best cod fisheries) swarms of this large species can be seen from the jetties. It is therefore noteworthy that it can occur in Californian waters, where its presence indicates the presence of a genuine cold water influence derived from arctic sources. North Sea waters are insufficiently cold for this species. The writer has never found it in frequent collections made over a period of years in northern Scottish waters, although it is said to have occurred there on one occasion.

B. THALIACEAE:

Species	AUSTRALIA M.V. "Warreen"	AUSTRALIA Great Barrier Reef Expedition	EAST INDIES Siboga Expedition (chiefly)	NORTH SEA	NEWFOUNDLAND AREA, S.T. "Cape Agulhas" (chiefly)
Cyclosalpa pinnata	+	+	+	+	-
" *affinis*	+	-	-	-	-
" *bakeri*	+	-	+	+	-
" *floridana*	+	-	-	-	-
" *virgula*	+	-	-	-	-
Brooksia rostrata	+	+	+	-	-
Ihlea magalhanica	+	-	-	-	-
" *punctata*	-	-	+	-	-
" *asymmetrica*	-	-	-	+	-
Salpa fusiformis	+	-	+	+	-
" *maxima*	+	-	-	-	-
" *cylindrica*	+	+	+	-	-
Ritteriella amboinensis	+	-	+	-	-
" *picteti*	+	-	+	-	-
Metcalfina hexagona	+	-	+	-	-
Thetys vagina	+	-	-	+	-
Pegea confoederata	+	+	+	-	-
Traustedtia multitentaculata	+	-	+	-	-
Thalia democratica	+	+	+	+	+
Iasis zonaria	+	+	+	+	+
Pyrosoma atlanticum	+	-	+	+	+
" *agassizi*	-	-	+	-	-
Doliolum denticulatum	+	+	+	-	-
Dolioletta gegenbauri	+	+	+	+	-
Total	21	8	18	9	5

There is therefore no evidence of a genuine cold water influence, even in Tasmanian waters, although in the latter region species which are characteristic of warm-temperature as well as of circumtropical waters are those most usually found (e.g. *Ihlea magalhanica*, *Iasis zonaria*, and *Thetys vagina*). There is a complete and noteworthy absence of typical antarctic species such as *Oikopleura weddeli*, *O. valdiviae*, *O. gaussica*, *O. drygalski*, and *Fritillaria antarctica*.*

(ii) It will be seen from the above tables that the areas with particularly rich *demersal* fisheries and at least moderate pelagic fisheries (the North Sea, Newfoundland, and, it may be added, Iceland, where, in a cruise round the island in 1925 the writer, in 36 hauls of a 12 in. fine silk net, obtained only two species - *Fritillaria borealis* f. *typica* and *Oikopleura labradoriensis*, but where the two other species of Copelata taken in the Newfoundland area can also be found) only a very few species of pelagic Tunicates occur. On the other hand, Japan and California, which have rich *pelagic* fisheries in addition to moderate demersal fisheries, yield a much higher number of species of pelagic Tunicates. This is so since, in addition to a restricted

* Mr. K. Sheard informs the writer that he thinks it is also true that no true antarctic crustacean species occurs in these collections, though sub-antarctic species occasionally occur in Tasmanian waters, especially in the deeper water layers.

number of colder water forms, a large number of warm water forms occur - and, it must be remembered, pelagic Tunicates are characteristically found in the warmer waters of the circumtropical regions. It may be concluded therefore that the Californian and northern Japanese* regions benefit greatly from the convergence of waters drawn from arctic and tropical sources. On the data, this admixture cannot be demonstrated to occur in the Australian or East Indian regions, where, as also in the region of the Philippines, and probably also in the southern Japanese region, only the species characteristic of circumtropical waters occur, although the total number of species is large.

(iii) The probability that the Australian region has a greater affinity with the above-mentioned regions in the west Pacific than with the Californian region in the East Pacific is also suggested by a further examination of the evidence. Of the 23 south-eastern Australian species of Copelata, 19 are found also in Japanese waters, whereas only 13 of them have apparently been recorded from Californian waters. (In each of the two latter areas *Fritillaria venusta* and *Appendicularia sicula* occur; these species have not yet been recorded from the S.W. Pacific). As has been mentioned above, Australian waters differ also in the absence of cold water species. It is quite possible that more extensive collections than have yet been made in the southern Japanese area may indicate the presence of one or more of the species *Althoffia tumida*, *Bathychordaeus charon*, *Oikopleura parva*, and *Fritillaria bicornis*, found in S.E. Australian waters. *Fritillaria tenella* has been taken in the East Indian area as well as that of Japan, but may be identical with *F. megachile*, which occurs freely in the Australian region. Indeed, if we except the occurrence of the two colder water species (presumably limited to the northern Japanese area), there is a remarkable resemblance between the Japanese area and that of south-easteran Australia.†

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* Graham (1941), in a study of the distribution of species of the Dinoflagellate Genus *Ceratium*, shows the position of transition (at the subpolar convergence) from warm to cold water species off the north-east of Japan.

† Cognate information on the comparative distribution of the tuna fishes, kindly communicated by Dr. D.L. Serventy, also indicates this closer relationship between the south-eastern Australian and the Japanese region, and shows that seven species found in S.E. Australian waters are also found in Japanese waters. Only four of these are taken in the Californian fisheries.

	S.E. Australia	Japan	California
Thunnus germo (Albacore)	+	+	+
Neothunnus macropterus (Yellowfin)	+	+	+
Katsuwonus pelamis (Striped tuna)	+	+	+
Auxis thazard (Frigate mackerel)	+	+	+
Euthynnus alleteratus (Mackerel tuna)	+	+	
Kishinoella tonggol (Northern tuna)	+	+	
Gymnosarda nuda (Dog-tooth tuna)	+	+	
Total	7	7	4

(*Sarda australis*, or Bonito, may yet be proved to be conspecific with the Californian species *Sarda chiliensis* and with one of the Japanese species. The Australian species *Thunnus maccoyii* or southern bluefin has allied but not identical forms in both the other regions. *Cybiosarda elegans* is restricted to Australian waters.)

In the Australian region, the more prolific species of Thaliaceae - *Thalia democratica*, *Oikopleura longicauda*, and *Doliolum denticulatum* - outnumber *Salpa fusiformis*, *O. rufescens* and *Dolioletta gegenbauri* respectively. The reverse is the case in Californian waters. This is a point of considerable importance. Again, although the number of species of Doliolida found in the Australian area is very restricted, yet we must note the absence of *Doliolina mulleri*, which is found off the Californian coast. (This species has been recorded by Garstang as rare in certain New Zealand waters). Complete information on the Thaliaceae of Japanese waters is not available for comparison.

Summarising the indications arising out of a comparative study of the pelagic Tunicates in the various regions concerned, we find that the Australian region appears to be closely allied in character to the Western Pacific area, including the East Indies, the Philippine Islands, and the southern Japanese area, since not only do the same species tend to occur in all cases, but the occurrences are limited to species characteristic of warmer waters, and the predominant species (numerically) are the same. There is a lesser number of species common to the Australian area and that of California, and the conditions in the former region must be considered to differ rather substantially from those in the latter, since cold water forms are also entirely absent from it and the predominant species (numerically) are different.*

On these analogies it is therefore a distinct possibility that the development of the pelagic fisheries of Australia will on the whole follow the western rather than the eastern Pacific pattern.

2. Characterisation from Total Amount of Plankton Available.

Although it has frequently been concluded in the past that plankton is generally richer in cold than in warm water areas, the reverse has been found to be the case in regard to pelagic Tunicates, which are generally most abundant in circumtropical regions. This latter finding has been repeatedly confirmed. Jespersen (1935), for example, found that the comparatively large volumes of plankton taken in the Indo-Malayan region by the "Dana" were chiefly due to salps. This author made an important contribution to the data on the relative amounts of plankton in waters of different temperature. A good rough impression of the quantitative distribution was obtained by using throughout (in the Pacific ocean) a stramin net with circular opening of 1½ metres' diameter, the hemp fabric having 4-5 strands per centimetre. As shown in Fig. 5, the volume (number of cubic centimetres of plankton taken per hour of horizontal hauling) varied considerably. Large volumes, due according to the author to the cold Peruvian (Humboldt) current, were secured in the eastern part of the Pacific to as far as the Marquesas Is., with a distinct maximum west of the Galapagos Is. (incidentally a favourite tuna fishing region). Further west, to as far as the Fiji Is., the quantities decreased to much smaller dimensions, but increased again towards New Caledonia, becoming large in the New Zealand area. Relatively small quantities were, however, taken in the whole western portion

* Mr. K. Sheard informs the writer that on going through the Chilton collection he has been struck by the resemblance existing between some of the littoral Amphipods along the line: East Australian Coast —> Philippines — Japan. On the other hand Talitrids and Amphithroids appear to predominate in the littoral zone along the eastern Pacific coast, while Gammarids and Pontogeneids predominate on the western Pacific coasts. There is also a striking resemblance between Australian Amphipods and Cumacea (littoral) and those of areas such as the Gulf of Siam.

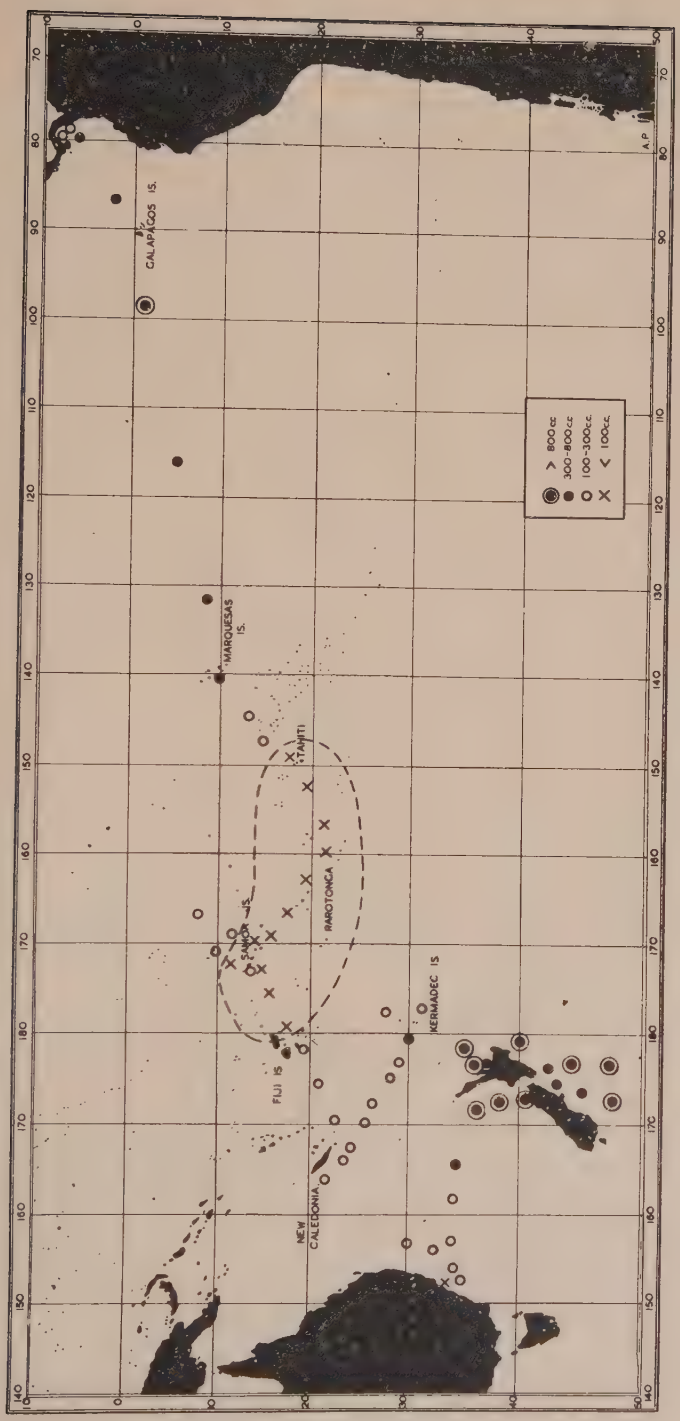

Fig. 5 - Mean volume of macroplankton in hauls with 1½ m. stramin net at different stations in the Pacific and Tasman Sea. (After Jespersen, 1935).

of the Tasman Sea, near Australia. The richest hauls (except in Panama Gulf) occurred usually in the upper water layers. The mean volumes ranged from 185-565 cc. and bore a distinct relation to the quantity of nutritive salts (nitrate and phosphate) in, and to the temperature of, the the water. Larger quantities were taken in the open ocean than close to the land. In the upper layers the mean volumes were 262 cc. in the Gulf of Panama, 626 cc. at the Marquesas Is., from 89 to 111 cc. between the Marquesas Is. and New Caledonia, 950 cc. in the New Zealand area, and 373 cc. in the Tasman Sea, where however, volumes were greater in the east than in the west. The fall in volumes from east to west in the Tasman Sea was associated with a rise of temperature (from about 15°C. to about 23°C.) in the same direction. (Fig. 6).

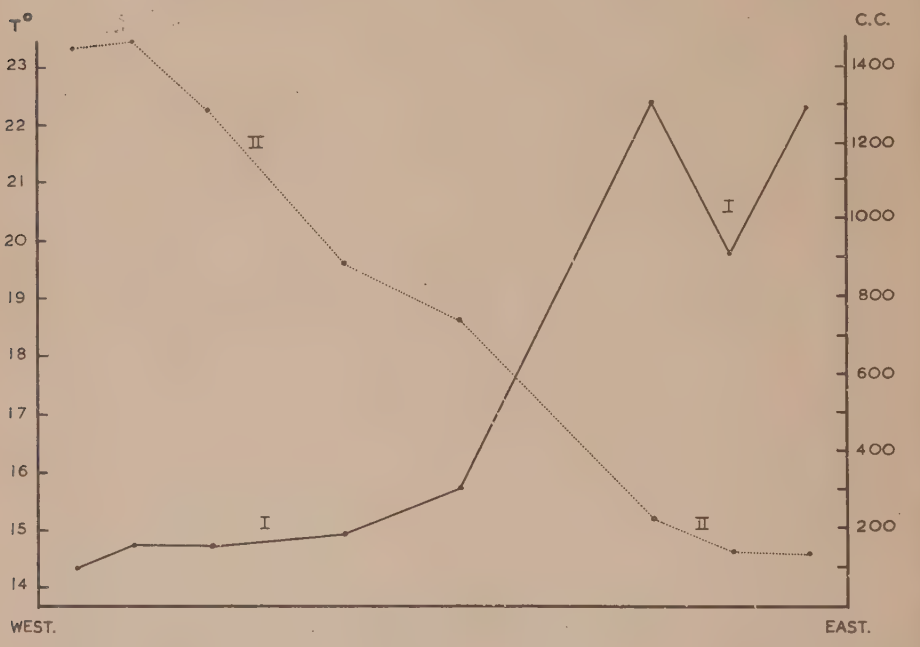

Fig. 6 - Mean volume of macroplankton in hauls with 1½ m. stramin net (I) and temperatures at a depth of 50 metres (II) on a section across the Tasman Sea. (After Jespersen, 1935).

The author points out that in most tropical and temperate regions the volumes in the deeper layers are much less than in the upper layers. The Gulf of Panama, where the hydrographic conditions are peculiar, furnished an exception to this rule, which does not always hold in colder areas. For example, McIntosh (1937) shows that the few species which in places make up the bulk of the Antarctic macroplankton are mainly concentrated in the surface water in summer, but descend (several hundreds of metres) to very deep water in winter, and that there is very little doubt that this phenomenon is normal and general in the higher latitudes of the Southern Ocean, where the vertical movements of water masses are considerable in extent. Such movements do not apparently take place near the Australian coast, where, as is shown later in this paper, the plankton has been found to be aggregated chiefly near the surface; and where, in the plankton hauls of the Barrier Reef Expedition, the maximum quantity of salps was taken at the depth of 10 metres, the quantity being found to diminish rapidly below 15 metres.

Delsman (1939) refers also to the lack of vertical mixing in the more tropical waters, where there is constant heating of the surface layers and no succession of warm and cold seasons as in temperate and cold regions; he states that mixing may however be caused locally by constant offshore winds or the passage of a strong current over a submarine ridge, and that, where there is a scarcity of nutritive salts or lack of their renewal by mixing, no rich plankton can develop, and no abundant fish population can be expected. Some figures are quoted for the phosphate content of different regions and depths. From a low figure (approx. 5 milligrammes per cubic metre) of P_2O_5 at the surface in the Java Sea, the amount increases, as in other regions, with depth. Below 200 metres a uniform content of 100 mg. per cu. metre is obtained down to 3,000 metres. At the surface, as the coast is approached, the amount increases (owing to mixing due to convection, or to offshore winds); it is also higher towards the polar and sub-polar regions. Thus between 40° and 50°S. Lat. values of 21 to 51 mg. are found, while between 50° and 60°S. Lat. the figures vary from 51 to 81 mg. and even higher. For the Barrier Reef Region Orr (1933) found a relatively uniform value of 5 mg. (rarely as high as 8 mg.) i.e. a somewhat similar amount to that obtained in the Java Sea. For the water off the Sydney (New South Wales) coast, rather larger values for phosphate were obtained by Dakin & Colefax (1935) who found that the values were on the whole very stable during the year, averaging at the surface from about 15 to 20 mg. They compare this with other areas - e.g. with surface water of the English Channel (varying from 0 to 8 mg. in summer to about 30 mg. in the colder months from October to March inclusive); and with the cold waters of the Antarctic, where the value never goes below 50 mg. and frequently exceeds 100 mg. These authors state that on the whole, therefore, the coastal waters off New South Wales approximate more in phosphate content to English Channel conditions, except that exhaustion of P_2O_5 does not occur in the summer - in other words, a seasonal cycle is not so pronounced. When outbursts of phytoplankton growth deplete the phosphate, the latter is usually fairly quickly regenerated from somewhat deeper water. They reach the conclusion that in the waters off the Sydney region both nitrate nitrogen and phosphates are present in what might be termed medium quantity. Graham (1941) reports values of 25 - 75 mg. P_2O_5 per cubic metre from the waters off the Californian coast, and of more than 100 mg. at points off the Peruvian coast. He states that the latter high values probably represent the combined effect of local upwelling and of the Humboldt Current.

In making deductions from the low phosphate and nitrate content of tropical waters, and the very moderate content of sub-tropical waters such as those off the south-east Australian coast (which is the chief centre of the existing Australian fisheries) some caution should be used. As Hardenberg (1938) points out, the lack of salts in the warmer regions may be partially counteracted by accelerated growth of organisms and by the more rapid metabolism generally associated with higher temperatures. Riley (1939) suggests that although the gross productivity of the southern (western Atlantic) waters is, according to his investigations, only half as great as that of the northern, the greater transparency of the water allows photosynthesis to proceed down to three times the depth, so that the total productivity per unit area of the warmer regions may be equal to or greater than that of temperate regions. He found the total number of animals to be less in tropical waters than in those further north, but to be about equal to the annual mean for certain other temperate regions - e.g.

the English Channel and the North Sea, as well as for the tropical waters of the Great Barrier Reef Lagoon. Russell (1934) makes a comparison between the latter region and some northern European waters, stating that the Barrier Reef zooplankton is as rich numerically as that of such regions as the Cattegat, the North Sea, and the English Channel, where however the plankton is possibly not as rich as in still more boreal waters. He also directs attention to the consideration of speed of metabolism, which, taking Delsman's results, is probably four or five times as fast in tropical as in cool waters.

Dakin & Colefax (1940) discuss at some length the evidence on which comparative estimates of the productive capacity of warm and cold waters have been based. Caution is urged by them in the making of generalisations in the absence of fuller evidence. It is pointed out that some groups (e.g. radiolarians and polychaetes) are most abundant in the tropics, and that rich as well as poor regions for plankton can occur there; also that in comparing volumes of plankton taken in different hauls, allowance must be made for the season of the year, and for proximity to the coast. Consideration should also be given, they continue, to the higher speed of metabolism found in warm regions. They imagine that their catches of diatoms made off the New South Wales coast are greater than those made by the Barrier Reef Expedition but probably less than the best made round England and not nearly as great as those which have been taken off the Californian coast (where we may note there is upwelling of cold water and a rich pelagic fishery). On the other hand, they express the opinion that there appears at least to be an abundance of crustaceans in the Australian region they studied, and that this would serve as fish food. In fact, they consider their catches of zooplankton to be comparatively good, tunicates as well as crustaceans being abundant at times; hence, while admitting the importance of Jespersen's study referred to above, they point out that they have frequently taken much larger volumes of plankton (with a smaller net than that used by Jespersen) than the low mean of 37 cc. found by the latter for catches made near Sydney. Reference to the table in Section VI of this paper (p. 36) will show that the average volumes taken by half hour horizontal tows of the 70 and 100 cm. nets of M.V. "Warreen" - both much smaller than the 150 cm. net used by Jespersen in tows of one hour - greatly exceed the very small figure quoted above*. It will also be shown in a later publication that while vertical mixing is certainly not pronounced on or off the south-eastern Australian continental shelf, there exist localised swirls of some importance as far as their effect on the plankton and the fisheries is concerned. Thus, while it must be left to more intensive and precise research to assess the relative fertility of warm and cold waters, there seems little doubt that the south-eastern Australian region exhibits at least a moderate degree of productivity, and that at least a moderately successful pelagic fishery is a possibility (just as a moderate demersal fishery on the very limited continental shelf has already been developed). The vast dimensions of the pelagic fisheries of California - where colder and mixed water influences are present - or of the demersal fisheries of the colder waters of northern latitudes, may however be too much to look for; for on the whole it is likely that the postulate of greater productivity of mixed and of cold waters is well founded.

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* Best results are however usually achieved close to land. Thus Clarke (1940) found in coastal water volumes about four times greater than those obtained over the continental slope of the Western Atlantic.

While this may well be so, one is tempted to suggest that it is highly probable that the greatly increased number of species in warmer waters - many of them coarse and even inedible large fish - sets up a severe drain on the total available supply of food organisms. The limited numbers of the more merchantable species would as a result be at a disadvantage as compared with those of colder waters. In other words, though there may well be a moderately good basic food supply in warmer waters, an undue proportion may go into an "ill skin". Apart from this, the number of predator species is high.* Aids to success under such conditions would be the development of protective devices (spines, protective coverings, etc.) and of speed - and associated wide radius of action - the latter ideally developed in the tuna fishes. The comparison is indeed a striking one with the complete lack of a protective spinose or leathery cuticle, and with the comparatively limited migrations, in the case of the few but plentiful edible fish species of a colder area like the North Sea or the Newfoundland Banks, where, incidentally, large predator species appear to be few in number.

Quantitative plankton investigations have in the past been based chiefly on the Atlantic and Indian Oceans by various expeditions (e.g. the "Plankton", "Tiefsee", and "Sudpolar"). The more recent "Barrier Reef","Dana", and "Discovery" expeditions have to some extent carried the work into the Pacific and Southern Oceans. A standardized technique and set of nets has not been used by all, hence comparisons are often difficult or impossible to make between the various results of these efforts. As has been stated above, a tendency has more recently developed to question the universal validity of the earlier deduction that general productivity of plankton is greatest in the colder waters. No reason has however been found to question the conclusion that a greatly increased number of species inhabit the warmer waters. The investigations reported upon in this paper certainly support the latter conclusion as far as pelagic Tunicates are concerned. With regard to total productivity, however, they support the hypothesis that in at least some groups of the zooplankton - of which Tunicates are emphatically one - productivity in warmer waters can equal or exceed that in colder waters.

The writer has, using chiefly the catches of the N.70 ("Discovery" type) fine silk net or its equivalent, carried out an extensive survey of the relative numbers of pelagic Tunicates in North British, Iceland, Newfoundland, and Labrador, and south-eastern Australian waters.

The average numbers of Copelata (Appendicularia) taken by vertical hauls of the N.70 net, passing through 100 metres of water in the surface layers (not deeper than 200 metres) was:- Iceland - 294 (75 in the colder water of the north, and 600 in the warmer water of the south); North British - 809 (over one-third of which were the very small species *Fritillaria borealis*); Newfoundland - 2746 (or 764, if *F. borealis* be omitted); S.E. Australia - 655 (practically all medium or large sized species).

If these catches of Copelata were expressed in terms of total volume or food value, there would not be a great deal to choose between these regions, except that two of the colder regions (Iceland and Newfoundland) would appear to

* According to Mr. K. Sheard (private communication) the number of predatory species among crustaceans is also higher in warm than in cold waters.

display opposite tendencies if taken as a whole. Only two species were taken (the hauls were made in spring) at Iceland, and one of these - *Oikopleura labradoriensis* - occurred only in the south, and in negligible numbers. Hence a volumetric estimate would have yielded very poor results, owing to the very small size of *F. borealis*. Particularly would this be the case in the cold north. The Newfoundland catches (made all over the area equally in spring and autumn - the numbers taken were four times greater in spring than autumn) were undoubtedly the best, but again, if *F. borealis*, numerically preponderant, be omitted, the numbers taken were not substantially larger than those taken in the Australian region, which would indeed probably show greater actual volumes on account of the larger sizes of many of its species. It is thus seen that as far as the Tunicate group Copelata is concerned, greater average amounts are to be taken in the sub-tropical Australian than in the sub-arctic and boreal Iceland region, and somewhat comparable amounts with those taken in other boreal and temperate regions. Similarly Lohmann (1914) found that the numbers of Copelata taken by the "Valdivia" Expedition in the west-wind drift and Antarctic waters were fewer than in the warm regions traversed. Actually, the best haul was taken near the equator and was five times as great as the best haul taken in the Baltic Sea. He indicates that in polar as in warm regions large populations can be found, but that the tropics have the advantage of an all-the-year round production, as against a short productive season in the polar region.

With regard to the other chief division of pelagic Tunicates (chiefly salps) the writer has found an overwhelmingly greater population in the Australian region. A few species occasionally stray into the North British area along with the influx of Atlantic water in late summer or autumn, but the average catch of the N.70 net (per 100 metres hauled through would be virtually zero. This holds also for the Iceland and Newfoundland regions, where salps etc. were so seldom encountered that no numerical tally was worthwhile. For example, in the Newfoundland area a few species such as *Iasis zonaria*, *Salpa fusiformis*, *Thalia democratica*, and *Pyrosoma atlantica* can be taken at times, but only well out in Atlantic water, beyond or just on the margin of the banks, where the influence of the Gulf Stream is felt.

Taken all over, therefore, it is certain that, as far as the pelagic Tunicates are concerned, the advantage in total productivity lies heavily on the side of the warmer regions, in which is included the south-eastern Australian region. It may be added that these Tunicates enter to some extent into the food supply of fishes.

VI. TOTAL PLANKTON IN THE SOUTH-EASTERN AUSTRALIAN REGION.

In an important work, Dakin & Colefax (1940) demonstrated, for the first time in the Southern Hemisphere, a seasonal cycle in plankton production of a kind similar to that so well known for the colder waters of the Northern Hemisphere. They showed, from a long series of studies made in the waters in the locality of Sydney, that total plankton is least plentiful in the winter season. Then in August comes an outburst of growth of the minute plant life of the sea (phytoplankton - e.g. diatoms and dinoflagellates) which persists till early

in November, declines later in November and in December, and then flourishes again on a lesser scale during a secondary productive period in late summer and autumn (January to March). The authors point out - and this is noteworthy - that in certain years the spring outburst of growth can occur somewhat earlier - in July instead of August.

The zooplankton, depending primarily for its food supply on this phytoplankton, was found to follow a somewhat similar cycle of development, though naturally at somewhat later periods of the year. On the whole, this animal plankton multiplied in late spring or early summer, and tended to maintain itself at a high level during summer and autumn.

The authors found that, as in the Northern Hemisphere, there are variations in the time of onset of the spring maximum of the phytoplankton and in the grade of development in different years. For example, indications were found that 1932 was an "earlier" year than either 1931 or 1933.

The analysis that follows serves, on the whole, to confirm these findings, and in some respects it amplifies them considerably, since it is based on rather voluminous and representative material secured during nearly three years in both inshore and offshore waters in the whole area from South Queensland to Southern Tasmania.

1. Distribution with Reference to Latitude.

For purposes of reference, the area from north to south was divided into rectangles or zones, whose dimensions correspond to one degree of longitude and latitude respectively. These zones were numbered serially from (1) south of Tasmania to (22) in the Capricorn region off southern Queensland. (Figs. 1 and 2). They were in certain cases treated as units of area - e.g., averages of all hauls made within each unit were calculated in order to determine how the density of plankton-distribution varied from north to south. The results were as follows:-

Net		
N. 70 (Vertical)	Depth 50 - 0 Metres:-	Best zones 14 - 6. Average volumes of total plankton per haul in zones with 5 or more hauls vary from 19 to 91 cc.
	" 100 - 50 Metres:-	Best zones 17 - 7. Averages in zones with 5 or more hauls vary from 8 to 47 cc.
	" 250-100 Metres:-	Best zones 15 - 6. Averages in zones with 5 or more hauls vary from 9 to 41 cc.
	" 500-250 Metres:-	Very uniform. Twelve out of the 15 zones sampled gave averages of just over 20 cc. The averages in zones with 5 or more hauls varied from 19 to 25 cc.
N. 70 (Horizontal)		Best zones 21 - 6. The averages in zones with 10 or more hauls varied from 84 to 793 cc.

N.100 (Horizontal)	Best zones 18 - 2. The averages in zones with 10 or more hauls varied from 93 to 859 cc.
N.200 (Horizontal)	Best zones 21 - 2. The averages in zones with 10 or more hauls varied from 147 to 1770 cc.

The range of variation therefore tended to increase in the half-hour horizontal tows (which were made in the surface layers), as compared with the short vertical tows, and was greatest in the case of the largest net. It is noteworthy that, below 250 metres' depth, there is apparently more uniform (and we will see later, less dense) distribution. The dense patches or swarms of plankton organisms which cause the fluctuating catches seem therefore to be largely confined to upper water layers.

In attempting to discern whether there is actually a most favoured centre of density, we see that although some nets show a restriction of the best catches to the more centrally placed zones - say from zones 17 to zone 6 - others show that good average hauls can be made in any latitude. It is not allowable to sum the quantitative results for all the nets, since the variations found in the larger nets would obviously cloak those found in the smaller nets; but, by allocating a serial figure to each zone, according to the position occupied by it in each of the complete series of net catches, and then calculating the average position taken by each zone, we find that zone 9 consistently yielded the highest catches, and zone 10 the second highest. (These zones contain the well-known rich fishing grounds - e.g. those of the Bermagui region for tuna).* Either one or the other of these zones regularly and easily took first place, independently of type of net used. Third and fifth places were occupied by zones 6 and 3 respectively (i.e. those off the east Tasmanian coast, from Babel Island southwards), and the fourth place by zone 14, off the northern New South Wales coast. Sixth, seventh, and eighth places were taken by zones 11, 8, and 12 respectively, in the areas north and south of the premier zones 9 and 10. The remaining places in the list were distributed further to north and south. Thus off the extreme northern New South Wales coast and the southern Queensland coast (e.g. in zone 21 - the Hervey Bay region - which took 9th place) comparatively low results were nearly always yielded, and it may be noted that this northern area has not on the whole been found to be one rich in large pelagic fish shoals. On these results there would appear to be no clear reason for subdividing the area - e.g. by treating Tasmanian results separately - in the further analysis of the data which follows.

2. Comparative Volumes Taken at Various Depths.

For this study we have available the results of the N.70 fine silk net, hauled vertically from 50-0, 100-50, 250-100, 500-250 and 1000-500 metres respectively and automatically closed in the latter four cases on reaching the upper limit of depth. The volumes taken were as follows:-

* From Figs. 1 and 2 it is seen that it is at about this level of latitude that most of the more tropical Tunicate species tend to fade out. The mean annual temperature of the water also tends just below 20°C. here and it is worthy of note that Graham (1941) found, with reference to the distribution of Ceratia in the well-known Kuro-Sio and Gulf Stream currents, that the tropical floras change their facies rather rapidly when the surface temperatures drop below 19°C.

Depth (metres)	Total volume (cc.) per 50 metres.	No. of hauls	Average volume per haul (cc.)
50-0	10266	239	43 *
100-50	1631	102	16 *
250-100	564	88	6 *
500-250	350	85	4
1000-500	4	1	4

These results suggest that the plankton in general is chiefly concentrated in the upper 50 metres layer of water. Jespersen (1935) also found that in most tropical and sub-tropical regions the volume of plankton was small in the deeper layers. It seems therefore that in the case of future work the most economically obtained and representative information can be secured by making more frequent hauls in this depth zone, devoting to this purpose the disproportionate amount of time occupied by working in deeper water. This is advisable since only by increasing the frequency of sampling can the difficulties presented by the uneven distribution of plankton organisms in the upper water layers be - partly at least - overcome.

The density of occurrence, as indicated by the above figures, appears to diminish somewhat sharply (to amounts of between 1/2 and 1/3 from stage to stage) as observation passes from the upper 50 metres to the second 50 metres, and from the latter to depths lying between 100 and 250 metres. Below 250 metres the rate of diminution slows down and the figures suggest that there is a rather even distribution (at a density around 1/10th of that in the uppermost water layers) down to a considerable depth. It is of interest in support of this suggestion to recall from the previous section that the total plankton appeared, at a depth of between 500 and 250 metres, to be remarkably evenly (though sparsely) distributed in the horizontal or lateral sense, from north to south. Lohmann (1933), summarising the highest catches of Copelata made by the Plankton Expedition at various depths, shows a somewhat similar order of diminution to that outlined above. Kokubo & Tamura (1931) also found that it seemed that, in Aomori Bay, Japan, the general trend was that in summer the abundance of plankton is highest in the upper layer and that it decreases with depth; with the advance of the season the distribution becomes homogeneous from the surface to the bottom.

* a. Assuming perfect filtration by the net these volumes would give averages of 2.26, 0.84, and 0.32 cc. of total plankton per cubic metre of water in the 50-0, 100-50 and 250-100 water layers respectively.

b. Clarke (1940) states that 0.54 cc. would be a typical average volume per cu.m. in the coastal and offshore areas of the west Atlantic; but

c. Kokubo and Tamura (1931) for Aomori Bay, Japan, deduced much higher volumes, ranging from below 1 cc. to 252 cc., which they contrast favourably with

d. Apstein's (1906a) values of from below 1 cc. to 56 cc. for the North Sea. Obviously critical tests under uniform conditions would have to be carried out to supplement these results, which, even making allowances for average depth worked in, and for season, tend to show comparatively poor values in the cases of (a) and (b).

These results as a whole are of some significance when it is considered that, as will be shown in the following section, the major occurrence of plankton is confined roughly to a six or seven months' season, during which most of the shoaling of pelagic fish near the surface is observed. This shoaling is manifestly for feeding purposes. With the onset of the "off" season for plankton - i.e. the season when plankton is reduced in the surface layer to a density more in accordance with that found more uniformly, and practically throughout the year, at greater depths - there would be few if any plankton swarms in the upper water layers to cause schooling of fish; on the contrary, the latter, having concluded a season of "high" feeding such as we know occurs in the annual cycle of such bottom-feeding fishes as the cod and haddock of the Northern Hemisphere, may quite conceivably, as in the case of these fish, maintain themselves on a subsistence diet for the balance of the year, and become more scattered, both laterally and in relation to depth. Certainly the somewhat similar state of dispersion of the plankton, together with its comparatively low level of density, make this a feasible explanation of the general non-occurrence of pelagic fish shoals in the surface zone during the colder portion of the year. An apparent exception - the schooling of pilchard during the winter months off the northern New South Wales coast - can be explained on the score that this is a spawning aggregation of fish; and in any case, the schools are often located at a considerable depth, coming only occasionally to the surface.

3. Monthly and Seasonal Distribution.

(a) Monthly distribution:

In the following table are set out the average catches (volume in cubic centimetres) made, in the whole area under consideration, in each month of the year (except March, in which no sampling was carried out). The period covered extended from May 1938 to January 1941. The averages were calculated from varying numbers of hauls, the range of these numbers being given in the bottom line of the table.

NET	(1) N.70 Vert. (50-0 m.)	(2) N.70 Horiz. (upper 25 m.)	(3) N.100 Horiz. (upper 25 m.)	(4) N.200 Horiz. (at surface)	(5) N.70 Vert. (100-50 m)	(6) N.70 Vert. (250-100m.)	(7) N.70 Vert. (500-250m.)
May	17	135	61	242	11	18	15
June	14	287	235	557	13	23	27
July	11	175	97	319	12	6	13
Aug.	15	108	48	263	6	9	23
Sep.	46	435	302	1002	20	23	24
Oct.	53	593	738	711	20	18	29
Nov.	82	658	661	2403	13	39	22
Dec.	53	260	236	760	20	10	17
Jan.	59	207	155	355	37	31	18
Feb.	87	295	482	1305	13	10	12
Apr.	25	148	174	245	7	12	20
Hauls No.	13 to 32	5 to 45	11 to 51	5 to 40	6 to 12	5 to 12	5 to 12

Curves showing the seasonal trend of these monthly averages for the first four nets, hauled in the surface or near-surface waters, are shown in Fig. 7. It is apparent that in all cases the most productive season extends through spring and summer from September to February (there are no figures for March). However in three cases out of the four there is a slight decline in December, becoming more pronounced in January, and a secondary rise in June. Apart from this latter rise, the density of the plankton is definitely low during the late autumn and winter months. The peak month appears to occur usually in the October-November period, being thus placed somewhat later than the phytoplankton maximum noted by Dakin & Colefax (1940).

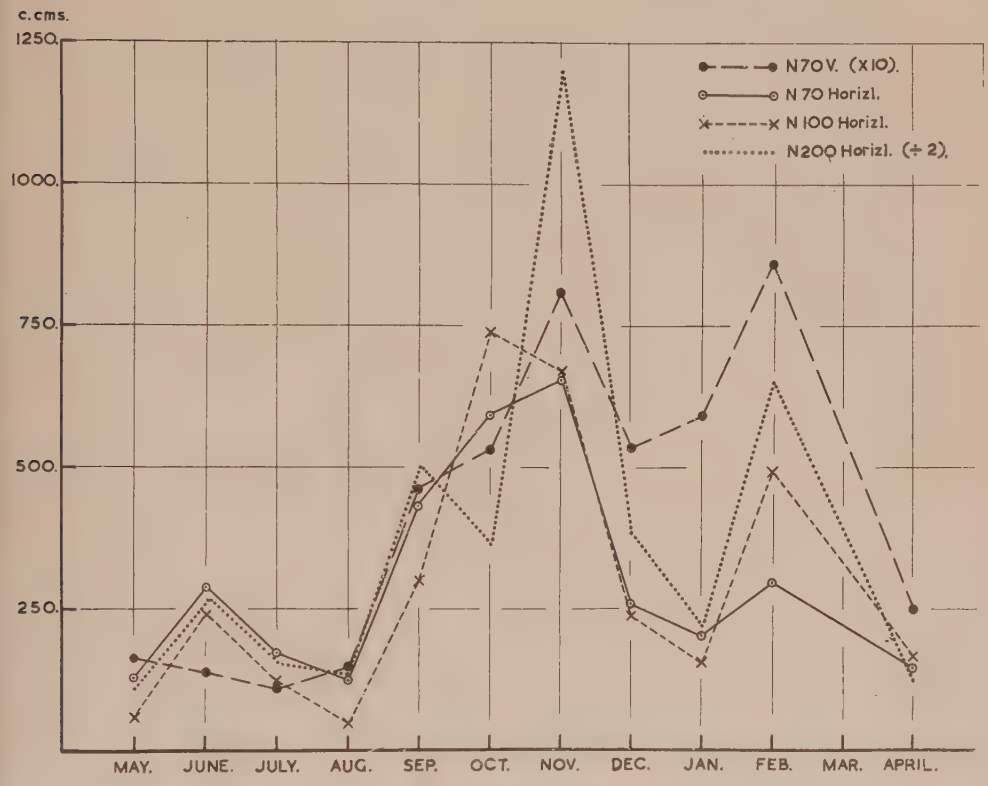

Fig. 7 - Total Plankton. Monthly average volumes (cc's) using various nets.

The curves for the different years can show variations. Thus there were indications (for which the evidence is not included here) that in the year 1939 peak figures were attained earlier (in September) than in 1938, the secondary decline also being earlier (in October and November) followed by a rise again in December, January, and February. The data for 1940 were less extensive, but such few hauls as were made failed completely to show the spring rise, although by summer (January, 1941) the volumes had become more normal for that period of the year. It is of interest to note that the year 1940 was, in the fisheries, quite an abnormal one, being characterised by a general scarcity of

fish, a more southerly distribution than usual of certain species (e.g. northern bluefin tunny), and the appearance of an unusual number of tropical forms. The run of bluefin tuna also began and finished late, and the Tasmanian scallop season was late. It was also shown shown above (see p.16), in considering the occurrence of specific pelagic Tunicates, that in 1939-1940 an unusual number of the more tropical forms was captured.

As a matter of interest the results for the Tasmanian region alone were also worked out independently in order to determine whether the rich and poor seasons differed in time of incidence from those noted off the mainland. No difference was found, the major spring-summer and the minor June rises being again disclosed. Here again no reason was found for the separate treatment of data from the Tasmanian region.

These trends are in general still apparent in the fifth and sixth series in the above table, which refer to results from vertical hauls from 100 to 50 and from 250 to 100 metres respectively. However in the seventh series, relating to hauls made between the greater depths of 500 and 250 metres, we see distinct evidence indicating a considerable degree of uniformity of distribution over the whole year. This accords well with similar evidence of uniformity, referred to in a previous section, in terms of hauls made in varying latitudes from north to south.

(b) Seasonal distribution:

Having determined that there is, except in the deep water layers, a well-marked difference in the density of the total plankton between the warm season and the cold season of the year, it is worthwhile to attempt to arrive at a rough quantitative estimate of this difference.

By assembling the volume-of-catch data within the periods March-August and September-February respectively the following series of average volumes (in cubic centimetres) was obtained:-

	1. March to August		2. Sept. to Feb.		Volume Ratio 2/1
	Av. volume	No. of hauls	Av. volume	No. of hauls	
(1) N.70 Vertical (50-0 m.)	16	97	61	142	3.81
(2) N.70 Horizontal (upper 25 m.)	145	80	381	150	2.63
(3) N.100 Horizontal (upper 25 m.)	100	110	384	185	3.84
(4) N.200 Horizontal (at surface)	286	68	949	142	3.32
(5) N.70 Vertical (100-50 m.)	10	41	22	57	2.20
(6) N.70 Vertical (250-100 m.)	13	38	24	51	1.85
(7) N.70 Vertical (500-250 m.)	19	37	22	48	1.16

In the first four series, referring to average catches by different nets in the upper water layers, there is a general similarity in the ratios between catches made in the warmer and the colder seasons respectively. The indication is that the density of the plankton in the warmer season is rather more than three times as great as that in the colder seasons. If the figures for the Tasmanian region are taken separately this ratio also holds. It follows that, in conducting scientific research on the plankton, best results and greatest economy of effort will accrue from confining most of the work to the warmer season of the year.

However, an examination of the ratios derived from the 5th - 7th series, made with closing nets at successively increasing depths, discloses that there is a distinct probability that the seasonal differences become less and less apparent as the depth increases, until, below a depth of 250 metres, there is ostensibly no difference in the density of plankton distribution, summer or winter.

Clarke (1940) from a comparison of total volume of plankton taken at different seasons in the Western Atlantic found that from twenty to forty times more was taken in the coastal area in the warm half of the year than in winter. Over the continental slope the ratio was still ten times greater, but no significant seasonal change was found in the Sargasso Sea, where temperatures are higher, ranging from 19° to 27°C. The seasonal change in volumes in the south-eastern Australian area is of an intermediate nature between the two latter. It is noteworthy that the greatest numbers of pelagic Tunicates are not universally present in the warmest months of the year. The latter is generally the case, occurring according to the writer's observations in British and Newfoundland waters, and according to Chevey (1939) in the waters of Indo-China. In the case of Copelata, however, Lohmann (1933) states that in the Mediterranean many fewer are taken in the warm than in the cold seasons; and Essenberg (1926) found the greatest numbers in the San Diego region of California in the cooler months of the year.

4. Annual Variation in Relative Productivity.

The following table shows the average catches (volume in cubic centimetres) in successive calendar years.

	1938 (May to December)			1939			1940			1941 (January)		
	Totals	No. of hauls	Avr. per haul	Totals	No. of hauls	Avr. per haul	Totals	No. of hauls	Avr. per haul	Totals	No. of hauls	Avr. per haul
N.70 Vert. (50-0 m.)	3227	63	51	3836	99	39	2200	60	37	1030	19	54
N.70 Horiz. (upper 25 m.)	29635	42	706	23963	105	228	9939	60	166	5208	23	226
N.100 Horiz. (upper 25 m)	44633	76	587	26669	134	199	7067	61	116	3745	24	156
N.200 Horiz. (at surface)	61443	39	1575	67390	89	757	17220	61	282	7106	21	338

It will be observed that all four nets show, in their average catch-per-haul results, a progressive decrease in volume from 1938 through 1939 to 1940. This would suggest that the total available plankton was, within the period under review, greatest in amount in 1938. It may be mentioned, without attempting at this early stage in these investigations to correlate cause with effect, that a fairly general fish scarcity had developed by 1940, and extended into 1941. For example, the tuna fishery showed somewhat the same decreasing trend as the plankton.

For the year 1941 there were available at the time of writing only the average results for January. These would appear to show some increase from the general averages for 1940, but they should be compared with the averages for January (1940) as follows:-

	N.70 Vertical	N.70 Horiz.	N.100 Horiz.	N.200 Horiz.
January 1940	75	250	196	370
January 1941	54	226	156	338

A continuance of the fall, rather than a recovery, is indicated by these figures.

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APPENDIX I.

LIST OF SOUTH-EAST AUSTRALIAN PELAGIC TUNICATA.

PHYLUM - TUNICATA

CLASS I: Copelata or Perennichordata: Appendiculariae.

CLASS II: Acopa or Caducichordata:
Sub-Class: Thaliaceae (with Pyrosoma).

CLASS I: APPENDICULARIAE = Copelata = Perennichordata.

Family I: Oikopleuridae
Sub-Family 1: Oikopleurinae

Genus 1: *Oikopleura* Mertens
Sub-genus: *Coecaria* Lohmann
Oikopleura longicauda Vogt
Oikopleura cornutogastra Aida
Oikopleura intermedia Lohmann
Oikopleura fusiformis Fol

Sub-genus: *Vexillaria* Lohmann
Oikopleura parva Lohmann
Oikopleura albicans Leuckart
Oikopleura cophocerca Gegenbaur
Oikopleura rufescens Fol
Oikopleura dioica Fol

Genus 2: *Folia* Lohmann (not represented in Australian catches)

Genus 3: *Megalocercus* Chun
Megalocercus huxleyi Ritter

Genus 4: *Stegosoma* Chun
Stegosoma magnum Langerhans

Genus 5: *Chunopleura* Lohmann
Chunopleura microgaster Lohmann

Genus 6: *Pelagopleura* Lohmann (not represented in Australian catches)

Genus 7: *Althoffia* Lohmann
Althoffia tumida Lohmann

Sub-Family 2: Bathochordaeinae

Genus 8: *Bathochordaeus* Chun
Bathochordaeus charon Chun

Family II: Fritillaridae
Sub-Family 1: Fritillarinae

Genus 9: *Fritillaria* Quoy and Gaimard
Sub-genus: *Acrocercus* Lohmann
Fritillaria formica Fol
Fritillaria haplostoma Fol
Fritillaria fraudax Lohmann

Sub-genus: *Eurycercus* Lohmann
Fritillaria borealis Lohmann (f. *sargassi*)
Fritillaria bicornis Lohmann
Fritillaria megachile Fol
Fritillaria pellucida Busch

Genus 10: *Tectillaria* Lohmann
Tectillaria fertilis Lohmann

Sub-Family 2: Appendicularinae.

Genus 11: *Appendicularia* Fol (not represented in Australian catches)

Genus 12: *Kowalevskia* Fol
Kowalevskia tenuis Fol

CLASS II: ACOPA = Caducichordata.

Sub-Class I: THALIACEAE
Order I: PYROSOMIDA
Family I: Pyrosomatidae

Genus: *Pyrosoma* Péron
Pyrosoma atlanticum Péron

Order II: CYCLOMYARIA
Family I: Doliolidae

Genus 1: *Doliolum* Quoy and Gaimard
Doliolum denticulatum Quoy and Gaimard

Genus 2: *Dolioletta* Borgert
Dolioletta gegenbauri Uljanin

Order III: DESMOMYARIA
Family I: Salpidae

Genus 1: *Cyclosalpa* de Blainville (= *Dolichodaea* Metcalf)
Cyclosalpa pinnata Forskål
Cyclosalpa affinis Chamisso
Cyclosalpa floridana Apstein
Cyclosalpa bakeri Ritter
Cyclosalpa virgula Vogt
(= *Salpa dolicosoma* Todaro)

Genus 2: *Brooksia* Metcalf
Brooksia rostrata Traustedt

Genus 3: *Ihlea* Metcalf (= *Apsteinia* Metcalf)
Ihlea magalhanica Apstein

Genus 4: *Salpa* Forskål (s. str.)
Salpa fusiformis Cuvier
(= *S. runcinata* Chamisso)
Salpa maxima Forskål
(= *S. africana* Forskal)
Salpa cylindrica Cuvier

Genus 5: *Ritteriella* Metcalf (= *Ritteria* Metcalf)
Ritteriella amboinensis Apstein
Ritteriella picteti Apstein
(= *Ritteriella retracta* Ritter)

Genus 6: *Metcalfina* Ihle
Metcalfina hexagona Quoy and Gaimard

Genus 7: *Thetys* Tilesius
Thetys vagina Tilesius(=*Salpa* costata Quoy and Gaimard: =*S. tilesii* Cuvier)

Genus 8: *Pegea* Savigny
Pegea confoederata Forskål
(= *Salpa scutigera* Cuvier)

Genus 9: *Traustedtia* Metcalf
Traustedtia multitentaculata Quoy and Gaimard (= *Salpa henseni* Traustedt: *S. verrucosa* Apstein; = *Traustedtia radiata* Metcalf)

Genus 10: *Thalia* Blumenbach

Thalia democratica Forskål (=*Salpa mucronata* Forskål)

Genus 11: *Iasis* (Lahille) Metcalf

Iasis zonaria Pallas (=*Salpa cordiformis* Quoy and Gaimard)

SPECIES NOT OBTAINED:

Oikopleura gracilis Lohmann
Oikopleura graciloides Lohmann
Oikopleura vanhöffeni Lohmann
Oikopleura labradoriensis Lohmann
Oikopleura weddeli Lohmann
Oikopleura valdiviae Lohmann
Oikopleura gaussica Lohmann
Oikopleura drygalski Lohmann
Oikopleura mediterranea Lohmann

Folia gracilis Lohmann

Megalocercus atlanticus Lohmann
Megalocercus abyssorum Chun

Pelagopleura oppressa Lohmann
Pelagopleura gracilis Lohmann
Pelagopleura verticalis Lohmann
Pelagopleura australis Bückmann
Pelagopleura magna Lohmann

Fritillaria abjörnseni Lohmann
Fritillaria gracilis Lohmann
Fritillaria aequatorialis Lohmann
Fritillaria antarctica Lohmann
Fritillaria drygalski Lohmann
Fritillaria helenae Bückmann
Fritillaria aberrans Lohmann
Fritillaria magna Lohmann
Fritillaria charybdae Lohmann
Fritillaria urticans Fol
Fritillaria venusta Lohmann
Fritillaria tenella Lohmann
Fritillaria scillae Lohmann
Fritillaria borealis (f. *typica*)

Appendicularia sicula Fol

Kowalevskia mossi Herdman (Garst.)
Kowalevskia oceanica Lohmann

Pyrosoma agassizi Ritter and Byxbee
Pyrosoma spinosum Herdman
Pyrosoma verticellatum Neumann
Pyrosoma hybridum Metcalf
Pyrosoma ellipticum Metcalf
Pyrosoma operculatum Neumann
Pyrosoma ahernosum Seeliger
Pyrosoma ovatum Neumann

Doliolina rarum Grobben -
Doliolina indicum Neumann
Doliolina intermedium Neumann
Doliolina resistibile Neumann
Doliolina müllleri Krohn
Doliolina Krohni Herdman
Dolioletta valdiviae Neumann
Dolioletta chuni Neumann
Dolioletta mirabile Korotneff

Ihlea punctata Forskål
Ihlea asymmetrica Fowler

II. STATISTICAL ANALYSIS OF DATA ON THE TOTAL PLANKTON.

By G.L. Kesteven, B.Sc.*

The standard 70 cm., 100 cm., and 200 cm. plankton nets were hauled at various times and places along the Eastern coast of Australia. The total plankton secured at each haul has been considered as a gross yield of living material at each station: the biological error† implicit in this approach may at this point be neglected and the direct question of variation among the yields secured may be considered immediately.

1. Problem:

Comparisons have been made in the text above between the mean yields of plankton from strata, squares, months, seasons, and years; the statistical problems involved may be stated as follows:

(a) What is the variance of the yields secured, and can that variance be analysed in order to assign portions of that variance to different sources;

(b) What is the validity of the comparisons which have been made, and can a statistical assessment be made of the significance of these comparisons?

2. Data:

The data consist of fourteen series of hauls as follows:-

N.70 Vertical 50/0, 100/50, 250/100, 500/250 (metres depth)
N.70 Horizontal 50/0, 100/50
N.70 Oblique 50/0, 200/100
N.100 Horizontal 25/0, 100/50
N.100 Oblique 50/0, 100/0
N.200 Horizontal 50/0, 100.

Those data were collected in the period May, 1938, to January, 1941, during which time the samples were taken somewhat haphazardly in respect of months and squares (geographical position) so that some months are poorly represented for some squares, and vice versa.

3. Methods:

The method used is the analysis of variance as devised by Fisher (1) modified by Yates (4) and described by Snedecor (2). Analyses of differences between variables were made generally on yield, but in the comparison of nets the ratio of the yield of one net to that of another was also used.

* Grateful acknowledgment is made of the assistance received in the whole of the work from Miss H. Newton Turner, McMaster Animal Health Laboratory, Sydney.

† Because of changes in the composition of the plankton, two hauls, although equal in volume, may be far from equivalent biologically: differences in the bulk of the individuals comprising the hauls will be of considerable importance. As a consequence it will be necessary eventually to prepare a series of biological coefficients so that the biological differences due to differences of composition may be allowed for, and volumes thus made directly comparable.

Because of the extreme variability of the data a logarithmic transformation was made; this was not done, however, on the ratios between nets, for these did not show the same wide ranges. For the transformed data the standard deviations and analyses of variance have been left in the transformed units.

Yates' method of analysis for disproportionate sub-classes, as set out in Snedecor (2) and in Snedecor and Cox (3) was used for the series N.70 V., H., and O., N.100 H. and O., and N.200 H., and for the four sets of ratios: the data in all these sets were non-orthogonal. It had been intended at first to separate the variance in each of these series according to squares, months, and nets, but because there were so many gaps in the data it was found necessary to make the comparison of the nets separately, and for each net in each type of haul to group the data in three seasons (February-May, June-September, October-January) and then to proceed to a disproportionate analysis of seasons against squares.

For the comparison of nets in horizontal and oblique hauls, and the comparison of strata in the vertical hauls with the N.70, the data are orthogonal and the analysis is straightforward.

4. The Comparison of Nets:

(i) The variance of the logarithms of original observations.

(a) Horizontal Hauls: On 59 occasions the three nets N.70, N.100, and N.200 were all used in the same stratum at the same station.

These 59 occasions were not all in the same month or year; some were in one square and some in others, so that, although in the analysis of variance the "between-nets" term is clear of other sources of variance, the between stations term contains portions due to squares, months, and years. The remainder term is a nets and stations interaction and not a true experimental error; it is a mixture of second and third order interactions.

As separation of these would be likely to reduce the magnitude of this term, it can safely be used to demonstrate the significance of the between-nets variance. If the between-nets variance is significant with this term as it stands, it would be more so with the true error.

The remainder term gives a standard deviation of 0.36.

Source	df	Sum of Squares	Mean square
Total	176	85.9247	
Between nets	2	7.7280	3.8640 xx
Between stations	58	63.1089	1.0881 xx
Remainder (nets and stations)	116	15.0868	0.1301
Mean - 2.345			
Standard deviation of single haul - 0.36			

(b) Oblique Hauls 50/0: There are 72 sets of hauls with two nets (N.70 and N.100) at the same station and in the same upper stratum. The analysis shows that whilst the between-stations variance, which again contains portions due to squares, months, and years, is to a moderate degree significantly greater (at the 5 per cent. point) than the remainder, the differences between the nets have no significance as compared with the remainder. The consequence is that no reliance can be placed on differences of yield obtained by the N.70 and N.100 nets in oblique hauls in the surface stratum, without further evidence on the variation between yields of each type of net taken at the same place at the same time.

Source	df	Sum of squares	Mean square
Total	143	70.1461	
Between nets	1	0.3588	0.3588
Between stations	71	41.6617	0.5868
Remainder (nets and stations)	71	28.1256	0.3961
Mean - 1.754 Standard deviation of a single haul - 0.63			

The remainder term gives a standard deviation of 0.63 which is nearly double the standard deviation of the horizontal hauls.

(c) Oblique Hauls 100/50: There are 54 sets of hauls in this lower stratum. The result is the same as for the surface stratum except that the between-stations variance (again with portions due to squares, years and months) has significance at the 1 per cent. point.

Source	df	Sum of squares	Mean square
Total	107	9.5226	
Between nets	1	0.0174	0.0174
Between stations	53	16.2177	0.3060 xx
Remainder (nets and stations)	53	1.7429	0.0329
Mean - 2.023 Standard deviation of a single haul - 0.18			

The nets and stations term gives a standard deviation of 0.18, which is half the coefficient for horizontal hauls and almost exactly one quarter of the coefficient for the oblique hauls in the shallower stratum.

(ii) The ratios of yields of pairs of nets used in the same stratum and at the same station.

Wherever two nets were hauled in the same stratum in the same manner at the same station, the ratio between their catches was calculated; the mean values and the standard deviations of these ratios are set out here. These latter include not only experimental error, but also differences due to squares, months, and years.

	Oblique	Horizontal		
	N.70/100	N.70/100	N.70/200	N.100/200
No. of ratios	129	68	206	46
Mean value	1.71	2.43	0.84	0.80
S.D.	1.91	4.52	1.3	0.35

The values of N.70 as compared with N.100 in both oblique and horizontal hauls indicate greater catching power on the part of the N.70, and it is probable that since the N.100 is of the wider mesh and therefore retains larger individuals in general, the smaller zoo-plankton (which would be principally small crustacea such as copepods) predominate in the plankton generally.

The question arises as to whether these mean values are dependent upon conditions prevailing in the squares and seasons in which the nets were hauled. The following analyses show that the ratio N.70/N.200 is dependent upon the square in which it was obtained, that the ratio N.100/N.200 is dependent upon square and season, and also that significant interaction exists.

N.70/N.100 Oblique

Source	df	Sum of squares	Mean square
Total	35	62.3058	
Between seasons	2	2.0980	1.0490
Between squares	11	17.2958	1.5723
Interaction	22	42.9120	1.9505
Experimental error	96		1.4370
Mean - 1.708 Standard deviation of individual hauls - 1.92			

N.70/N.100 Horizontal

Source	df	Sum of squares	Mean square
Total	23	162.4471	
Between seasons	2	10.9347	5.4673
Between squares	7	63.0573	9.0064
Interaction	12	88.4551	7.3713
Experimental error	46		9.4949
Mean - 2.431 Standard deviation of individual hauls - 4.52			

N.70/N.200 Horizontal

Source	df	Sum of squares	Mean square
Total	38	36.6452	1.5078
Between seasons	2	3.0156	1.3141 xx
Between squares	12	15.7691	0.6300
Interaction	22	13.8605	0.5107
Experimental error	173		
Mean - 0.836 Standard deviation of individual hauls - 1.30			

N.100/N.200 Horizontal

Source	df	Sum of squares	Mean square
Total	17	7.5619	0.4733 xx
Between seasons	2	0.9465	0.6497 xx
Between squares	5	3.2486	0.4208 xx
Interaction	8	3.3668	0.0596
Experimental error	30		
Mean - 0.802 Standard deviation of individual hauls - 0.35			

5. The Comparison between Types of Haul made with the Same Net:

(i) N.70 Vertical, Horizontal, and Oblique.

There are 73 sets of hauls made with the N.70 at the same station in the one stratum in each of the three types of haul. The between-hauls variance is clear of other sources of variance, but the between-stations variance again contains portions due to months, years, and squares. The remainder is again not a true experimental error.

Source	df	Sum of squares	Mean square
Total	221	88.7602	
Between hauls	2	25.8859	12.9430 xx
Between stations	73	46.6451	0.6390 xx
Remainder (hauls and stations)	146	16.2292	0.1112
Mean - 1.744 Standard deviation of a single haul - 0.33			

The between-hauls variance is significant, showing that the type of haul is important. The remainder gives a standard deviation of 0.33.

The differences are principally differences due to length of haul. The vertical hauls are short, passing through 50 metres only, while the oblique hauls are of much greater length, and the horizontal hauls are of ½ hour duration, covering about 1,600 metres.

Analysis has been made of the data in the two series N.70 V. and H. separately, regardless of whether or not such hauls were made at the same station at the same time. From these analyses the following standard deviations were obtained.

Vertical	0.38
Horizontal	0.86

These contain, of course, portions due to months, years, and squares, but as the type of haul was used at random at different places and times the comparison was considered valid. There is a greater variability among the horizontal hauls than among the vertical hauls.

(ii) N.100 and N.200:

The N.100 was hauled in oblique and horizontal hauls

in the same stratum at the same station on only one or two occasions and, therefore, no analysis is possible; the standard deviations for the two series N.100 O. and H. obtained as for paragraph (i) are:

Horizontal	0.73
Oblique	1.14

This result could be due to a greater possibility of nil and small yields when oblique hauls are made with this net if the larger organisms (which are captured by this net) tended to occupy the surface stratum.

The N.200 was hauled horizontally only, its standard deviation being 0.65.

6. The Comparison between Strata:

(i) The N.70 Vertical hauls 50/0, 100/50, 250/100, 500/250.

There are 75 sets of hauls made with the N.70 vertically in successive strata from 500 m. to the surface. The analysis shows significant differences between strata; the between-stations variance again contains portions due to months, years, and squares.

Source	df	Sum of squares	Mean square
Total	299	28.7915	
Between strata	3	66.1174	9.5972 xx
Between stations	74	23.9038	0.3230 xx
Remainder (strata and stations)	222	13.4221	0.0605
Mean - 0.868 Standard deviation of a single haul - 0.25			

In this comparison the standard deviation from the remainder term is 0.25 which is not far from the value obtained for the vertical hauls in the upper stratum alone (0.38).

(ii) Oblique hauls, N.70 and N.100 in pairs in 50/0, 100/50, and 100/0.

No direct comparison between these strata with these nets is possible because the two strata were not sampled together at any one station, either with one net alone or with both nets; however, the standard deviations given above in the comparison of the nets, 0.63 and 0.18 respectively, are comparable and indicate diminished variability in the lower strata. This prevails although the N.100 is hauled to the surface.

7. The Comparison between Squares and Seasons.

(i) N.70.

(a) Vertical Hauls: 212 hauls were made in 13 squares at irregular intervals throughout the period 1938-41 (the data from 2 squares were rejected on the score of incompleteness). The analysis shows that squares and seasons are highly significant and that there is also a significant interaction between these two. The presence of this interaction indicates that a mean for any square is dependent upon the season of sampling, and vice versa. This interaction indicates that a mean for any square is dependent

upon the season of sampling, and vice versa. This interaction also is a source of embarrassment in handling these data since the confounding of effects which it represents is a major reason why means and variances may not be extracted directly.

Source	df	Sum of squares	Mean square
Total	38	6.1173	
Between squares	12	1.4347	0.1196 xx
Between seasons	2	0.7819	0.3920 xx
Interaction	24	3.9007	0.1625 xx
Experimental error	173		0.0432
Mean - 1.323 Standard deviation of individual hauls - 0.38			

(b) Oblique Hauls: There are 58 hauls made in 10 squares (5 being rejected). The squares in this case are not significant and the seasons are only moderately significant; the interaction is quite significant, giving the same indications as above.

Source	df	Sum of squares	Mean square
Total	23	4.1909	
Squares	7	0.8702	0.1243
Seasons	2	1.5863	0.7932 x
Interaction	14	1.7344	1.2389 xx
Experimental error	34		0.1777
Mean - 1.951 Standard deviation of individual hauls - 0.54			

(c) Horizontal Hauls: In these hauls seasons, squares, and interaction are all without significance; this may be taken to be due to the increased experimental error which gives here a standard deviation of 0.86 (for individual hauls).

Source	df	Sum of squares	Mean square
Total	38	4.0991	
Seasons	2	0.4051	0.2025
Squares	12	1.4597	0.1216
Interaction	24	2.2343	0.0931
Experimental error	163		0.2041
Mean - 2.121 Standard deviation of individual hauls - 0.86			

(ii) N.100.

(a) Oblique Hauls: With this net in this type of haul squares and seasons and interaction are of no significance.

Source	df	Sum of squares	Mean square
Total	29	9.4914	
Seasons	2	0.0385	0.0198
Squares	9	2.6812	0.2979
Interaction	18	6.7717	0.3762
Experimental error	34		0.7546
Mean - 1.713 Standard deviation of individual hauls - 1.14			

(b) Horizontal Hauls: With this net in this type of haul the squares alone are of significance.

Source	df	Sum of squares	Mean square
Total	23	6.7848	
Seasons	2	0.4380	0.2190
Squares	7	4.6419	0.6631 xx
Interaction	14	1.7049	0.1218
Experimental error	66		0.1779
Mean - 2.147 Standard deviation of individual hauls - 0.73			

The possible meaning of the difference between these two standard deviations has been discussed above in Section 5 (ii). It possibly suggests that the N.100 should be used only in horizontal hauls.

(iii) N.200 Horizontal Hauls.

Analysis indicates that no significance can be placed on differences as to squares and seasons shown by this net in this type of haul.

Source	df	Sum of squares	Mean square
Total	35	5.4204	
Seasons	2	0.0485	0.0243
Squares	11	1.8591	0.1549
Interaction	22	3.5128	0.1597
Experimental error	146		0.1271
Mean - 2.455 Standard deviation of individual hauls - 0.65			

8. Summary and Conclusions:

The results obtained above may be summarized in the following table where + indicates a significant source of differences and - indicates absence of this. A dot indicates absence of data for testing.

Net and Haul	Between -				Sq.-Sn. Intern.
	Squares	Seasons	Strata	Haul types	
N.70 V.	+	+	+	}	+
N.70 O.	-	+	.	} +	+
N.70 H.	-	-	.	}	-
N.100 O.	-	-	.	}	-
N.100 H.	+	-	.	} +	-
N.200 H.	-	-	.	.	-

The results allow the following conclusions:

(i) Differences ascribed to nets in horizontal hauls are significant, but in oblique hauls they are not.

(ii) For the N.70, differences ascribed to squares are significant in vertical hauls only, those to seasons are significant in vertical and oblique hauls, while those to strata have been shown significant in vertical hauls only. The differences due to types of haul are reliable with this net. On the other hand the N.100 and N.200 yield significant differences only for the former as between squares in horizontal hauls, and between types of haul. The reliability of the N.70, particularly in vertical hauls, compared with the lack of reliability of the other nets suggests an efficiency of the N.70 in relation to the populations which it is able to sample and implies a lack of efficiency in the other nets in their relation to their populations. It seems that changes among the smaller plankton (see below) are best revealed by the N.70 in vertical hauls, and probably that changes among the larger plankton would be best observed by means of the N.100 in horizontal hauls.

(iii) The greater volumes of plankton taken by the smaller and finer-meshed net (N.70) as compared with those of the larger and coarser-meshed N.100 net, make it seem probable that from the latter net there escape the chief constituent of the plankton - viz., the smaller crustacea (copepods chiefly).

9. References.

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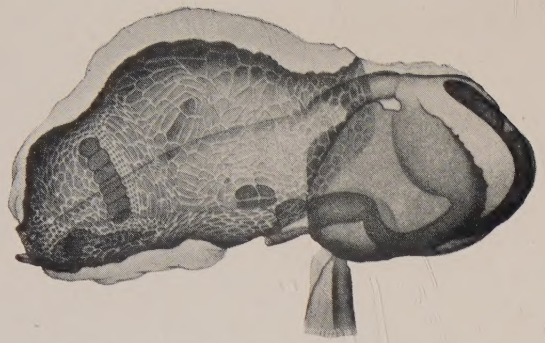

FIG. 1.—*Stegosoma magnum*, after Lohmann.

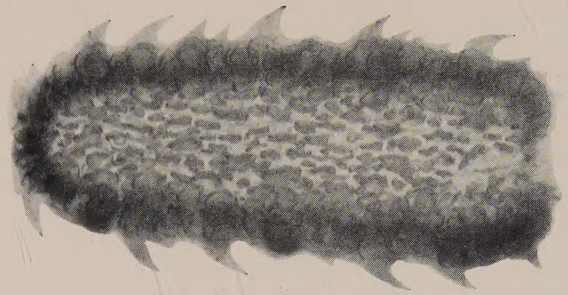

FIG. 2.—*Pyrosoma atlanticum*. Photo. A. Proctor.

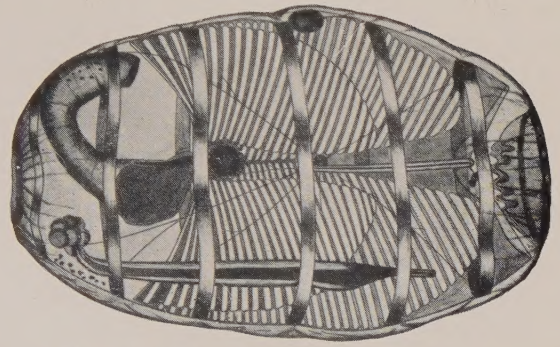

FIG. 3.—*Doliolum denticulatum*, A. Proctor del.

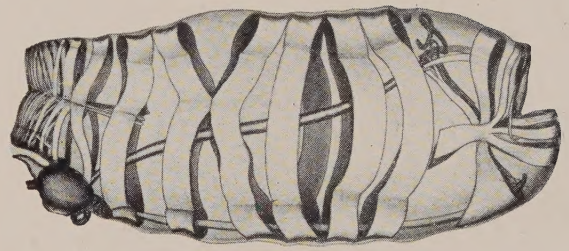

FIG. 4.—*Ihlea magalhanica*, F. V. Murray del.

PLATE 1.

The following list gives the

BULLETINS

numbered from 71 onwards.

A full list of the Council's publications is issued as a Supplement to the Council's Journal for February each year.

71. Investigations on Irrigated Pastures
72. Varieties of Wheat in Australia
73. A Soil Survey of the Nyah, Tresco, Tresco West, Kangaroo Lake (Vic.), and Goodnight (N.S.W.) Settlements
74. Observations on Soil Moisture and Water Tables in an Irrigated Soil at Griffith, N.S.W.
75. Nigrospora Musae n.sp. and its Connexion with "Squirter" Disease in Bananas
76. A Soil Survey of the Hundreds of Laffer and Willalooka, South Australia
77. Studies on the Phosphorus Requirements of Sheep.—I.
78. Methods for the Identification of the Light-coloured Woods of the Genus Eucalyptus
79. The "Lucerne Flea" Smynthurus viridis L. (Collembola) in Australia
80. The Establishment, Persistency, and Productivity of Selected Pasture Species on an Irrigated Reclaimed Swamp
81. A Comparative Study of Lolium perenne and Phalaris tuberosa at Varying Stages of Growth
82. The Insect Inhabitants of Carrion: A Study in Animal Ecology
83. Natural Pastures: Their Response to Superphosphate
84. The Basal (Standard) Metabolism of the Australian Merino Sheep.—II.
85. Studies on the Phosphorus Requirements of Sheep.—II. *(Out of print)*
86. A Soil Survey of the Berri, Cobdogla, Kingston, and Moorook Irrigation Areas, and of the Lyrup Village District, South Australia
87. Radio Research Board: Report No. 6
88. Radio Research Board: Report No. 7
89. Radio Research Board: Report No. 8
90. The Identification of the Principal Commercial Australian Timbers other than Eucalypts
91. Further Investigations into the Transport of Bananas in Australia
92. The Apple-growing Soils of Tasmania. Part 1: A General Investigation of the Soils. Part 2: A Soil Survey of Part of the Huonville District
93. Studies on Contagious Pleuro-Pneumonia of Cattle.—I.
94. Fertility in Sheep: Artificial Production of Seminal Ejaculation and the Characters of the Spermatozoa contained therein
95. Radio Research Board: Report No. 9
96. Observations on Myxomatosis Cuniculi (Sanarelli) made with a View to the Use of the Virus in the Control of Rabbit Plagues
97. Studies on Contagious Pleuro-pneumonia of Cattle.—II., II.(a), II.(b), III.
98. Cercospora Leaf-Spot (Frogeye) of Tobacco in Queensland
99. A Survey of the Pastures of Australia
100. Radio Research Board: Report No. 10
101. Radio Research Board: Report No. 11
102. Studies of Selected Pasture Grasses: The Measurement of the Xerophitism of any Species
103. Wojnowicia graminis (McAlp.) Sacc. and D. Sacc. in Relation to Foot Rot of Wheat in Australia
104. Investigations on the Occurrence and Inheritance of the Grass Clump Character in Crosses between Varieties of Triticum vulgare (Vill.)
105. Investigations on the Associated Growth of Herbage Plants
106. Investigations on "Spotted Wilt" of Tomatoes.—III. Infection in Field Plots
107. A Soil Survey of the Coomealla, Wentworth (Curlwaa), and Pomona Irrigation Settlements, N.S.W.
108. The Basaltic Soils of Northern Tasmania
109. The Variability of Plant Density in Fields of Wheat and its Effect on Yield
110. Radio Research Board: Report No. 12
111. Radio Research Board: Report No. 13
112. Studies in Fertility of Sheep

BULLETINS—*continued*

113. Studies on Coast Disease of Sheep in South Australia
114. The Wood Structure of some Australian Rutaceae with Methods for their Identification
115. A Soil Survey of Part of the Denmark Estate, Western Australia
116. The Relation of Phosphate to the Development of Seeded Pasture on Podsolised Sand
117. The Regional and Seasonal Incidence of Grasshopper Plagues in Australia
118. A Soil Survey of the Horticultural Soils in the Murrumbidgee Irrigation Areas, N.S.W.
119. The Wood Structure of some Australian Cunoniaceae with Methods for their Identification
120. Some Effects of Green Manuring on Citrus Trees and on the Soil.
121. Observations on the Toxicity of Fluorine for Sheep
122. The Establishment of Pastures on Deep Sands in the Upper South-East of South Australia
123. A Soil Survey of the Merbein Irrigation District, Victoria
124. The Wood Anatomy of Some Australian Meliaceae with Methods for their Identification
125. A Soil Survey of Part of the Kerang Irrigation District, Victoria
126. Investigations on Chilled Beef. Part I.—Microbial Contamination Acquired in the Meatworks
127. Radio Research Board: Report No. 14
128. An Investigation of the Problems of Salt Accumulation on a Mallee Soil in the Murray Valley Irrigation Area
129. Investigations on Chilled Beef. Part II.—Cooling and Storage in the Meatworks
130. Chemical Investigations on the Fleece of Sheep
131. Black End and Anthracnose of the Banana with Special Reference to Gloeosporium musarum Cke. and Mass.
132. The Wood Anatomy of Some Australian Lauraceae with Methods for their Identification
133. A Soil Survey of the Mildura Irrigation Settlement, Victoria
134. Studies on Bovine Mastitis. 1.—Study of an Experimental Herd
135. Investigations on the Storage of Jonathan Apples grown in Victoria
136. Experimental Studies of Ephemeral Fever in Australian Cattle
137. A Soil Survey of the Red Cliffs Irrigation District, Victoria
138. The Economic Biology of Some Australian Clupeoid Fish
139. The Soils of Tasmania
140. Foot-Rot in Sheep: A Transmissible Disease due to Infection with Fusiformis nodosus (n. sp.). Studies on Its Cause, Epidemiology, and Control
141. A Soil Survey of the Waikerie Irrigation Area, South Australia
142. A Soil and Land Use Survey of the Hundreds of Riddoch, Hindmarsh, Grey, Young, and Nangwarry, County Grey, South Australia
143. Production of Dried Grapes in Murray Valley Irrigation Settlements. 1.—Viticulture.
144. Interference in a Wind-Tunnel of Octagonal Section.
145. Friction and Lubrication: Report No. 1.
146. An Analysis of the Outbreaks of the Australian Plague Locust (Chortoicetes terminifera Walk.) during the Seasons 1937-38 and 1938-39
147. Enzootic Ataxia and Copper Deficiency of Sheep in Western Australia.
148. Studies in Fertility in Sheep. 2. Seminal Changes Affecting Fertility in Rams
149. Production of Dried Grapes in Murray Valley Irrigation Settlements. 2. Irrigation, Drainage, and Reclamation.
150. The Soils of the Parishes of Longford, Cressy, and Lawrence, County Westmorland, Tasmania.
151. The Control of St. John's Wort (Hypericum perforatum L. var. angustifolium D.C.) by Competing Pasture Plants.
152. Soil Survey of Part of County Moira, Victoria, including the Parishes of Boosey, Cobram, Katamatite, Naringaningalook, Katunga, Yarroweyah, and Strathmerton.
153. Pelagic Tunicates in the Plankton of South-eastern Australian Waters, and their Place in Oceanographic Studies.